DOCUMENT RESUME

ED 287 858 TM 870 559

TITLE	Psychological Sciences Division: 1985 Programs.
INSTITUTION	Office of Naval Research, Washington, D.C. Psychological Sciences Div.
REPORT NO	OCNR-11487-6
PUB DATE	Dec 85
NOTE	189p.
PUB TYPE	Reports - General (140) -- Reference Materials - Bibliographies (131)
EDRS PRICE	MF01/PC08 Plus Postage.
DESCRIPTORS	Adult Education; *Cognitive Processes; *Cognitive Psychology; *Decision Making; Group Behavior; Human Factors Engineering; Information Processing; Literature Reviews; Military Personnel; *Military Training; *Psychological Studies; Research Design; *Research Projects; Training
IDENTIFIERS	*Office of Naval Research

ABSTRACT

This booklet describes research carried out under sponsorship of the Psychological Sciences Division of the U.S. Office of Naval Research during Fiscal Year 1985. The booklet is divided into three programmatic research areas: (1) Engineering Psychology; (2) Personnel and Training; and (3) Group Psychology. Each program is described by an overview which is followed by thematic clusters of related efforts. Each cluster is described by individual projects, or work units, which were either completed or active during 1985. Each report of research is about one page, and includes scientific objectives, approach, progress, potential applications, and funding source. All work unit descriptions also include a listing of the technical reports and archival publications produced during the year. Most of the programs are basic in nature, with a selected augmentation of applied research and exploratory development effort. The range is from direct military decision making applications to instructional theories and computer-assisted instruction. (Author/MDE)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

Psychological Sciences Division

1985 Programs

OFFICE OF NAVAL RESEARCH

Arlington, VA 22217-5000

December 1985

This document is issued primarily for the information of U.S. Government scientific personnel and contractors. It is not considered part of the scientific literature and should not be cited as such.

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY
NONE

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE
NONE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release;
Distribution Unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
442-5

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Office of Naval Research

6b. OFFICE SYMBOL *(If applicable)*
Code 1142

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
Psychological Sciences Division - Code 1142
800 N. Quincy Street
Arlington, VA 22217-5000

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO

11. TITLE *(Include Security Classification)*
Psychological Sciences Division 1985 Programs (U)

12. PERSONAL AUTHOR(S)
Office of Naval Research - Code 1142

13a. TYPE OF REPORT
Summary Report

13b. TIME COVERED
FROM 1/1/85 TO 12/1/85

14. DATE OF REPORT *(Year, Month, Day)*

15. PAGE COUNT
178

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL
James T. Lester

22b. TELEPHONE *(Include Area Code)*
(202) 696-4503

22c. OFFICE SYMBOL
Code 1142CS

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

FOREWORD

This booklet describes research carried out under sponsorship of the Psychological Sciences Division of ONR during Fiscal Year 1985. The booklet is divided into three programmatic research areas: Engineering Psychology; Personnel and Training; and Group Psychology. Each program is described by an overview which is followed by thematic clusters of related efforts. Each cluster is described by individual projects, work units, which were either completed or active during 1985. All work unit descriptions include a listing of the technical reports and archival publications produced during the year. The report listings are not cumulative; information regarding reports published in previous years may be obtained from previous booklets in this series, from the Principal Investigators, or from this office.

Many of the technical reports cited are available from the National Technical Information Service (NTIS), Springfield, Virginia, 22161; or the Defense Technical Information Center (DTIC), Cameron Station, Building 5, Alexandria, Virginia, 22314. Your request will be expedited if you use the "AD number" which is given as part of the citation.

This is one of several means by which we communicate and coordinate our efforts with other members of the research sponsoring and performing communities. We encourage your comments about any feature of this booklet or about the programs themselves. If you wish further information, please do not hesitate to contact members of the staff listed in the Introduction. We welcome your interest in our programs and hope that you will continue to keep us informed of related research efforts.

W. S. VAUGHAN, JR

CONTENTS

FOREWORD i

INTRODUCTION iii

ENGINEERING PSYCHOLOGY PROGRAMS 1

A. Man-Machine System Interaction 2
B. Perception 13
C. Decision Making 24
D. Distributed Tactical Decision Making 32
E. Special Projects 40

Man-Machine Systems Technology 40
Defense Small Business Advanced Technology Program 40

GROUP PSYCHOLOGY PROGRAMS 48

F. Effective Heterogeneous Groups 49
G. Personnel Turnover and Retention 57
H. Productivity in Organizations 65
I Special Project: Manpower R&D Programs 77

PERSONNEL AND TRAINING RESEARCH PROGRAMS 94

J. Theory-Based Personnel Assessment 95
K. Information-Processing Abilities, Attention and Action 118
L. Instructional Theory and Methods 132
M. Cognitive Processes 155

INDEX 177

Contractors 177
Principal Investigators 179
Work Units (NR Numbers) 181

INTRODUCTION

Psychological Sciences Division programs are carried out under contracts awarded in response to unsolicited proposals. They are evaluated on the scientific merit of the proposed research, the facilities available for its conduct, the competence of the principal investigator, and relevance to Navy needs. The elements that shape our research program are scientific gaps and opportunities, and operational needs identified in Navy planning documents. Our overall aim is to support good science for the good of the Navy and the nation.

Most of the programs are basic in nature, with a selected augmentation of applied research and exploratory development effort. This mix of basic and applied research is developed and managed by the Division staff with the able assistance of other ONR scientists and with helpful guidance and advice from representatives of various Navy and Marine Corps activities. The programs seek to involve innovative civilian scientists in areas of research relevant to Navy and Marine Corps interests, and by so doing provide new perspectives, new insights, and new approaches to naval manpower, personnel, training, equipment and system design problems. This arrangement provides channels for information to flow back and forth between the civilian research community and the naval community, each keeping the other abreast of new developments. The emphasis is on the creation and exploitation of a cumulative scientific knowledge base upon which new technologies can be developed to improve effectiveness of Navy and Marine Corps men and women.

Continuous efforts are made to coordinate the Division's research program with other ONR contractors, with in-house Navy laboratories, and with the research sponsored by other services and other agencies. We work closely with research managers at the Navy Personnel Research and Development Center, the Chief of Naval Education and Training, the Naval Medical Research and Development Command, the Marine Corps, and the Naval Systems Commands and their laboratories and centers to promote the diffusion, extension, and eventual utilization of the knowledge obtained through the ONR contract research programs.

The Psychological Sciences Division is part of the Life Sciences Directorate, which also includes the Biological Sciences Division. Dr. Steven F. Zornetzer is Director for Life Sciences, and Commander Warren W. Schultz is the Deputy Director for Life Sciences.

The members of the staff of the Psychological Sciences Division are listed below:

Dr. W. S. Vaughan, Jr., Division Head (Acting)
Telephone (202) 696-4505

Engineering Psychology Programs:

Mr. Gerald Malecki, Program Manager (Acting)
Dr. Eugene E. Gloye*
Dr. John J. O'Hare
Telephone (202) 696-4290

Group Psychology Research Programs:

Dr. Bert T. King, Program Manager
Dr. James T. Lester
Telephone (202) 696-4209

Personnel and Training Research Programs:

Dr. Susan E. Chipman, Program Manager
Dr. Charles E. Davis
Dr. Michael G. Shafto
Dr. Harold L. Hawkins
Telephone (202) 696-4318

*Dr. Gloye is located at the ONR Detachment, Pasadena, 1030 East Green Street, Pasadena, California 91106; his telephone number is (213) 795-5971.

In addition to the headquarters personnel listed above, the following psychologists supported the program from the regional offices:

Dr. Nicholas A. Bond
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503
Telephone 813-401-8924

Dr. Richard E. Snow
Office of Naval Research Branch
223 Old Marylebone Road
London NW1 5TH England
Telephone 01-409-4471

ENGINEERING PSYCHOLOGY PROGRAMS

(CLUSTERS A-E)

Engineering Psychology Programs are concerned with assuring effective performance by personnel operating and maintaining the high technology equipment characteristic of modern Navy and Marine Corps systems. We seek better fundamental understanding of human motor, perceptual and cognitive behavior in order to develop general guidelines for the design of compatible interfaces between people and machines. Our program currently emphasizes theory-based research leading to process-oriented models which explain human behavioral characteristics.

The programs are organized into five clusters:

A. Man-Machine System Interaction: Objective of this cluster is to develop theoretical foundations of scientific knowledge about human limitations and capabilities in interacting with intelligent, adaptive computer-based systems. Current examples of research interests include interactive dialogue issues, resource theory for input/output modality design, algorithm manipulation in image processing, and cognitive compatibility issues in expert systems.

B. Perception: Objective of this cluster is to develop theories of perception in an information processing framework. Emphasis is on expansion of computational theories of human perceptual performance which account for both psychophysical and neurophysiological evidence.

C. Decision Making: Objective is to develop explanatory theory for behavioral, descriptive decision making. We emphasize programs of research which develop integrative models of the psychological mechanisms which produce characteristic behavioral phenomena in deductive and inductive inference, risk assessment and preference, and choice behavior in uncertain and incomplete information environments.

D. Distributed Tactical Decision Making: Objective is to develop an understanding of multiperson, cooperative decision making in complex, dynamic information environments. Research issues of current interest include strategies for decomposing complex problems leading to effective organizational arrangements; strategies for aggregating judgments, plans, and estimates over multiple decision makers leading to consensus-oriented choice; and strategies for concurrency models in rapidly changing, multi-operator environments.

E. Special Projects: These are exploratory development projects which extend the basic research program toward Navy application areas. A Man-Machine Systems Technology program includes research in three topic areas: supervisory control, design for maintainability, and decision-making in command-control systems. A Small Business Innovation Research program includes research with personalized/prescriptive decision aids in support of complex information-processing and decision-making task performance.

A. MAN-MACHINE SYSTEM INTERACTION

Research issues addressed in this cluster minimize concerns with the physical features of the man-machine interface and stress issues involved in cooperative, cognitive interaction with computer-based systems. Representative research topics currently include dialogue design characteristics, command and documentation language relative to software, resource theory for input/output device selection, perceptual theory implications for human-computer interaction in image processing, and cognitive consistency as a principle for interacting effectively with expert systems.

PILOT PERFORMANCE IN VERTICAL AND TRANSLATIONAL INSTRUMENT FLIGHT
NR 196-170
New Mexico State University/Roscoe

Scientific Objectives: The objective of this research is to develop a multiple regression model of helicopter and VTOL (vertical take-off and landing)pilot performance as a function of a large number of critical real-world variables and display dynamics variables, for aircraft having variable control dynamics.

Approach: The experimental approach involves the identification of flight information requirements, display and control design variables, and critical maneuvers representative of various classes of low-altitude, low-speed missions typical of VTOL flight operations. Experiments are conducted in an aircraft simulator, a variable-characteristic device that allows simultaneous manipulation of display and control system configurations and dynamics. To facilitate the investigation of relatively large numbers of system design and task variables simultaneously, economical fractional-factorial screening experiments precede the application of central-composite response surface designs. The resulting generalizable display and control design principles will provide guidance applicable to aircraft capable of vertical as well as translational flight with a high degree of maneuvering independence in six degrees of freedom.

Progress: The flight simulator has been programmed to simulate a generic VTOL aircraft with dynamic performance characteristics selectable over wide ranges of values by the experimenter. An integrated vertical and horizontal display and control system with selectable graphic and dynamic characteristics was also simulated. The horizontal display, which presents all information needed for precise vertical as well as translational maneuvering control, received the bulk of experimental attention and optimization early in the program with attention shifting to the forward-looking vertical display during 1985. Multiple regression models of the effects of experimental factors have been derived for each of three pilot performance measures.

Potential Applications: Initial application of the results of this program has been the transfer of software for display and control system generation to the Naval Air Development Center for further evaluation in advanced helicopter and VTOL simulations. There is a possibility of a similar transfer at NASA-Ames Research Center.

Funding: ONR; Naval Air System Command.

Reports:

Trujillo, E. J., & Roscoe, S. N. (1985) Horizontal display for vertical flight: A direction of motion experiment. (Tech. Report BEL-85-1/ONR-85-1). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory.

Wiedemann, J., & Roscoe, S.N. (1985). A multiple-regression model of pilot performance in vertical and translational flight. (Tech. Report BEL-85-2/ONR-85-2). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory. (AD-A161364)

SUPERVISORY CONTROL OF MAN-MACHINE SYSTEMS
NR 196-179
Massachusetts Institute of Technology/Sheridan

Scientific Objectives: This research investigates operator functions and performance in the supervisory monitoring and control of computer augmented man-machine systems. The technical objectives are to refine theories and construct models of operator performance that lead to a better understanding of factors affecting operator-computer interaction required for controlling dynamic system processes.

Approach: The technical approach involves both model formulation and man-in-the-loop experimentation. The modeling efforts focus on achieving representations of the operator's understanding of system processes and the representation of rules and knowledge underlying system functions. Experiments are conducted to test the stability of these models and to investigate parameters derived from the models that (a) mediate communication (queries and command inputs) and (b) facilitate effective feedback on system status. Experiments involve laboratory simulation of operator tasks for control of vehicles and dynamic plant processes.

Progress: Research during the past year has focused on the development of a structure and quantitative methods to represent component knowledge for computer models of dynamic systems and for mental models of the system operator. That work led to the concept of knowledge correspondence or calibration between the computer's model and the operator's model; measurement methods have been derived for assessing the degree of calibration. Experimental paradigms have been developed using action-state matrices which represent system operation in terms of input-output relationships. Experiments are being conducted: (a) to investigate methods and languages for the operator to communicate with the computer with regard to goals and understanding of system functions; (b) to assess factors that affect the calibration between the operator's and computer's models; and (c) to explore strategies for collaborative operator-computer interaction.

Potential Applications: The theory and models being developed will have potential application for enhancing operator planning and monitoring performance in advanced Naval systems employing supervisory control concepts. Underwater search and inspection vehicles, remote manipulators, and process control systems (e.g., power generation and propulsion systems) are examples of classes of systems to which new theories of supervisory control may be applied with the potential of significantly improving operational perfomance.

Report:

Sheridan, T.B., Roseborough, J., Charney, L. & Mendel, M. (1985). Interaction of human cognitive models and computer-based models in supervisory control (Tech. Rep.). Cambridge, MA.: Massachusetts Institute of Technology, Department of Mechanical Engineering.

USER-COMPUTER INTERFACE FOR HIGH RESOLUTION IMAGE PROCESSING
NR 196-182
The Catholic University of America/Howard

Scientific Objectives: In recent years many interactive image processing algorithms have been developed for transforming, enhancing, and reconstructing imagery data, but little research has addressed the ability of human operators to use them effectively. This project investigates both the perceptual consequences of various enhancement operators and the strategic or planning activities of users in this user-computer environment.

Approach: User/computer performance is examined in localization, recognition, and other image processing tasks. Static imagery is used to investigate the perceptual aspects of enhancement operators whereas dynamic, interactive tasks are used to investigate the strategic aspects of interactive imaging. Standard psychophysical measures are used to assess performance; operator transition networks and production rules are used to characterize the user-computer interaction.

Progress: Several experiments have been completed. One series has examined the role of spatial scale in the ability of observers to localize and classify simple gray-level images. Another has investigated how users apply enhancement operators in an interactive classification task. Additional follow-up experiments are underway.

Potential Applications: Interactive image processing systems are employed in anti-submarine warfare, anti-air warfare, surveillance, weather forecasting, and other Navy applications. The specification of perceptually-and cognitively-based user protocols for interactive imaging is useful in the design of such systems.

Archival Publications:

Howard, J.H., Jr., Shaw, R.J., Robertson, S.P., & Raver, J.A. (1985). User strategies in interactive image processing (p. 31-32). In Proceedings of The Human Factors Society 29th Annual Meeting. Santa Monica, CA: The Human factors Society.

Howard, J. H., Jr. (1985). Spatial scale in detection and recognition: Implications for image processing (p. 1114-1117). In Proceedings of The Human Factors Society 29th Annual Meeting. Santa Monica, CA: The Human Factors Society.

THE STRUCTURE OF INFORMATION IN SOFTWARE SYSTEMS
NR 196-191
George Mason University/Boehm-Davis

Scientific Objectives: Relational and associational models of programmer performance are investigated for an understanding of the forms in which data bases associated with software development are stored in the memory of programmers. Predictions of programmer performance are made and tested on data bases organized around hierarchical, network, and relational structures.

Approach: Software codes for three types of problems (resource allocation, sensor integration, and editing of address lists) are modified by experienced programmers according to a set of new specifications. The software code is presented in 3 different formats that vary along a representational dimension that depicts the decomposition of the problem: data-structure techniques, object-oriented techniques, and functional techniques. The effectiveness of each format type is experimentally evaluated in terms of the amount of time required to complete the modification, the number of errors made, and the number of modules that make up the software code which requires change.

Progress: Data have been collected on software programs decomposed with the three methodologies into data structures, functional structures, and object-oriented modules. The effectiveness of those decompositions has been evaluated using complexity and effort metrics. The modifiability of those software programs was assessed. Mental models utilized by the programmers have been inferred, cognitive-interface principles have been defined, and the dependencies between problem type and the quality of the resultant software program have been determined.

Potential Applications: Improvements in the understanding of the processes of programmer performance will lead to increases in software quality, productivity, and the design of techniques and tools that assure that the foregoing goals are met effectively.

Reports:

Archival Publications:

Boehm-Davis, D.A. (1985). Methodology and problem representation in programming. In Proceedings of The Human Factors Society 29th Annual Meeting. Santa Monica, CA: The Human Factors Society.

Boehm-Davis, D.A., & Ross, L.A. (1985). Program design methodologies: Structuring the software development process. In Proceedings of the IEEE Systems, Man, and Cybernetics Annual Meeting. New York: IEEE.

HUMAN FACTORS IN RULE-BASED SYSTEMS
NR 197-078
PAR Technology Corporation/Lehner

Scientific Objectives: This effort investigated the psychology of user interactions with knowledge-based systems. The focus of the work was on cognitive aspects of user/expert system interactions. The specific objective was to identify cognitive variables that robustly result in high-quality user interactions with knowledge-based systems.

Approach: Several experiments were performed comparing combined user/expert system performance under a variety of cognitive conditions. The primary variables manipulated were (1) cognitive consistency between the problem solving procedures encoded in the expert system and those utilized by the user, and (2) the user's cognitive model of how the expert system operates. Three experiments examined the interrelationship between cognitive consistency and the cognitive model in a small expert system for selecting alternative business stocks. A fourth examined the impact of the cognitive model on a user's ability to operate a medical diagnosis expert system.

Progress: The primary result of these four experiments was to show that a user's cognitive model has a dramatic effect on a user's ability to effectively interact with an expert system. Participants with a good cognitive model consistently and significantly outperformed participants with a poor cognitive model. This was a dramatic result since the experiments used a superficially weak manipulation of the cognitive model (viz., two pages of additional instruction that described general features of expert systems processing). The impact of cognitive consistency depended on the cognitive model variable. When participants had a poor cognitive model, consistency between the user's and machine's problem-solving approach led to more effective user interactions with the system. When participants had a good cognitive model, consistency had either a negative or a negligible impact.

Potential Applications: These results have significant implications for the design of the user interface of a knowledge-based system and other types of decision aid. First, if users are trained to have a good cognitive model of system processes, then those users will be able to adapt to a variety of alternative user interfaces. At the same time users with a poor cognitive model may not be able to effectively utilize the system, even if it has a so-called 'user friendly' interface. This suggests that the current concern with 'user friendly' interfaces is overemphasized. Alternatively, it suggests that a necessary ingredient of a 'user friendly' interface is that it promote a good cognitive model in users.

Reports:

Hall, R. (1985). Mental models and problem solving with a knowledge-based expert system (PAR Report No. 85-100). Reston, VA: PAR Government Systems Corporation.

Lehner, P.E., Rook, F.W. & Adelman, L. (1984). Mental models and cooperative problem solving with expert systems. (PAR Report No. 84-116). Reston, VA: PAR Government Systems Corporation.

Lehner, P.E. and Zirk, D.A. (1985). Cognitive factors in user/expert system interaction (PAR Report No. 85-107). Reston, VA: PAR Government Systems Corporation.

Lehner, P.E., Zirk, D.A., Hall, R.B. & Adelman, L. (1985). Human factors in rule-based systems: Final report (PAR Report 85-109). Reston, VA: PAR Government Systems Corporation.

COMMITTEE ON BASIC RESEARCH IN HUMAN FACTORS
NR 196-167
NAS-National Research Council/Deutsch

Scientific Objectives: This effort seeks to provide new perspectives on theoretical and methodological issues in human factors and to identify research and other mechanisms to strengthen and expand the scientific basis of human factors research and development.

Approach: The Committee is composed of 14 members with professional specialties in human factors and allied disciplines of psychology, engineering, cognitive and computer sciences, physiology, and sociology. The Committee is augmented by Working Group and Workshop members who provide intensive reviews of the state of the art and develop recommendations for advancing scientific theories and research applicable to human performance in human-machine systems.

Progress: Primary focus has been on the preparation of reports on a number of specific human factors topics for which there is a need for fundamental data and sound theoretical concepts. The reports address areas of human performance, such as methods for software design, human factors engineering data delivery systems, user-computer interaction, behavioral sciences in simulation, and supervisory control of complex systems. Also the Committee has established working groups and conducted workshops on the following topics: simulation technology to support human factors research development; design of computer software and effectiveness of programmer performance; the etiology of flight simulator sickness; and cognitive factors affecting the design of technical information systems. Other topics that are being examined include: theories and models of human performance in man-machine systems; cooperative and distributed decision performance; visual performance with multicolored display systems; and integrated ergonomic modeling.

Potential Applications: The results of this work will strengthen the scientific basis underlying the enhancement of human performance in high technology environments and will serve to stimulate the scientific community to address new theories and models of human performance.

Funding : ONR, AFOSR, ARI, NASA, and NSF.

Archival Publications:

National Research Council (1984). Research and modeling of supervisory control behavior: Washington, DC: National Academy Press.

National Research Council (1985). Methods for designing software to fit human needs and capabilities. Washington, DC: National Academy Press.

National Research Council (1985). Human factors aspect of simulation. Washington, DC: National Academy Press.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

DESIGN PRINCIPLES FOR THE SPECIFICATIONS OF COMPUTER SOFTWARE PROGRAMS
NR 196-175
Performance Measurement Associates, Inc.,/Connelly

Scientific Objectives: Interface principles were identified for software aids that contribute effectively to the joint efforts of system users and software analysts during the task of establishing requirement specifications. Theoretical issues investigated included: (a) Search techniques for non-programmer users; (b) Level of vocabulary appropriate for user-analyst communication; and (c) Transformations of a requirement statement that permitted a more complete specification.

Approach: An experienced software analyst worked interactively, via a computer terminal, with a specification writer who was a non-programmer but knowledgeable in the design of inventory systems, to develop a software-requirement specification. Experiments were designed to investigate the effectiveness of various aid designs for the achievement of a least-cost requirements specification. Time and effort to produce a requirements specification were measured for vocabulary levels that ranged from non-abbreviated commands in a restricted-function low-level vocabulary to a powerful vocabulary requiring minimal keying input. Various transformations of requirements specifications were presented to the user to assess their impact on the completeness of the specifications. The generality of the findings of the software design principles were validated by the performance of non-programmer writers of software requirements specifications.

Results and Conclusions: Sophisticated software aids are necessary to help the non-programmer user in the efficient search of least-cost specifications. When user-analyst communications were conducted over a period of 1-4 hours, the increased time required to recall the more powerful aids and command abbreviations was not compensated by either their brief input time or improved efficiency. Further, that effect appeared to be a function of command type and usage.

Potential Applications: Productivity and quality can be enhanced in the design and organization of software requirements; software aids that jointly serve the system user and software analyst can assist in the achievement of those design goals.

Technical Report:

Connelly, E.M. (1986, June). Investigation of the process of developing requirements specifications: Final Report. Reston, VA: Performance Measurement Associates, Inc .

THE STRUCTURE OF INFORMATION IN SOFTWARE CODE AND DATA BASES
NR 196-183
General Electric Company/Boehm-Davis

Scientific Objectives: Design parameters oriented by data structure, the object, or the function of the problem, were examined for their effectiveness in the organization and integration of information.

Approach: Working programs for non-trivial problems were produced from specifications by the use of alternate techniques that emphasized data structure, the object, or the function of the problem to be solved. The production code developed by a group of experienced programmers under the experimental conditions was evaluated for its quality, the effort required to produce it, its use of machine resources, and the consistency of the problem solutions among the participants.

Results and Conclusions: Objected-oriented methodologies led to better performance in the updating of software modules than techniques organized around either data structures or operations such as functional decomposition. Object-oriented techniques rely partially on data structures and partially on operations as the basis for structuring programs. The objected-oriented methodologies allowed programmers to adopt strategies for dividing the task of maintaining software code into more manageable parts consistent with their internal representation of that task. This practice permitted reductions in design time and in the complexity of the design solution, and the improvements were more effective with specific types of program tasks.

Potential Applications: The identification and validation of principles for structuring a software program, specification of software-developed guidelines, and the determination of cost-effective trade-offs for that development, will assist significantly in the task of software acquisition and management.

Reports:

Boehm-Davis, D.A. (October 1984). Approaches to structuring the software development process (Tech. Rep. GEC/DIS/TR-84-B1V-1). Arlington, VA: General Electric Company, Data & Information Systems. (AD A147694)

Boehm-Davis, D.A. (October 1984). On the structure of information in software: Final Report (Tech. Rep. GEC/DIS/TR-84-B1V-2). Arlington, VA: General Electric Company, Data & Information Systems. (AD A147580)

Archival Publications:

Boehm-Davis, D.A. (1984). On the structure of information in software (p. 546). In Proceedings of The Human Factors Society 28th Annual Meeting. Santa Monica, CA: The Human Factors Society.

THE IMPORTANCE OF SPECIALIZED COGNITIVE FUNCTIONING FOR TASK PERFORMANCE

NR 196-186
University of Pittsburgh/Gordon

Scientific Objectives: Determine whether a cognitive profile reflecting specialized tasks associated with the left or right cerebral hemisphere can be a useful predictor of job performance. Part I of the project was aimed at predicting successful Naval Aviators and other specialized jobs such as computer programmers. Part II focused on the relationship between the cognitive profile and job complexity of middle managers.

Approach: The cognitive profile was assessed with the Cognitive Laterality Battery (CLB). The Battery is a group of tests selected to assess functions attributed to the right and left hemispheres of the brain. The CLB was presented on 35mm slides and audio tape to groups of participants. Performance on each subtest as well as on each of 2 factors, the difference between the factors, and the sum of the factors were the independent (predictor) variables.

The dependent variables in Part I were the successes and failures of student pilots. These were obtained in 3 ways: 1) by success or failure in the program, 2) performance ratings obtained by flight instructors during training, and 3) flight scores from the Aviation Flight Jackets. In Part II the dependent variable was job complexity, which is defined as the number of different task components as well as the inter-dependence of one component on the next in a given job. About 1100 student naval aviators were tested for Part I; and about 120 individuals from business and industry were tested in Part II.

Results and Conclusions: Results demonstrated a significant superiority in visuospatial skills normally attributed to the right hemisphere for those who completed the aviation program. The same tests were given to individuals in management-related occupations; results did not clearly support the idea that successful managers were those with a visuospatial profile.

Potential Applications: The application of specialized cognitive function tests will be useful for designated job-selection and job-match situations.

Reports:

Gordon, H.W., Curnow, C.M., & Leighty, R. (1985). Specialized cognitive function as a risk factor in combat pilot selection, presented at the Annual Meeting of the International Neuropsychological Society, Denver, CO.

B. PERCEPTION

Perception is viewed as computation and the projects in this cluster begin to develop this theoretical approach to understanding early processes in human vision. The projects seek to combine computational modeling and psychophysical experiments at successive stages of data representation that begin with retinal intensity arrays and progressively construct the dynamic three-dimensional visual world. Computational theories provide both psychology and neurophysiology with testable models of the processes and implementation mechanisms that underlie human vision. This program is intended to result in an understanding of human visual processing sufficient to guide manipulation of artificial visual environments, e.g., computer-generated imagery, in ways that create natural perceptual responses.

INFERENCES FROM IMAGES
NR 196-188
Massachusetts Institute of Technology/Richards & Ullman

Scientific Objectives: To develop a mathematical theory of how a visual system can make reliable inferences about surface properties and 3D structure, given only 2D image intensities. For example, given only the intensity fluctuations in a region of an image, assess whether or not the intensity values could have arisen only from a surface consisting of water in motion.

Approach: This problem is investigated in four stages: (1) computer graphics, (2) mathematical analysis, (3) algorithm development, and (4) psychophysics. The first step, now completed, is to generate a realistic surface of water or wood using computer graphics. Such generation requires a reflectance and surface model that makes explicit all the perceptually relevant physical parameters. Two types of parameters appear important: (a) those of the reflectivity function, and (b) those that characterize the 3-D surface shape. For water, the key factors are hemispheric illumination of a Fresnel reflectance function, with the surface shape being the sum of non-linear sinusoids. For wood, the key factors are the appearance of elliptical contours that correspond to growth rings, intersected by line elements (wood grain) parallel to the major axis of these ellipses. Given these surface properties, experiments test whether they uniquely describe either wood or water, and demonstrate that these properties can indeed be recovered from the 2D image. Finally, once algorithms have been written that will examine a portion of a computer image and deliver a binary assertion about the nature of the surface patch viewed (i.e. water, wood, etc.), the behavior of these algorithms will be compared with psychophysical observations. If the successes and failures of the algorithm mimic human behavior, the model describes how observers see texture, such as water or wood.

Progress: Realistic rendering of water and wood have been completed using an Adage 3000 graphics system. A wide range of surface reflectance functions have also been explored to determine possible "false targets" -- surfaces that might look like water but have different physical properties. Image processing to extract the flow field characteristic of wood has been developed.

Potential Applications: This research will eventually contribute a foundation of basic knowledge about how to manipulate artificial imagery in order to create perceptual experiences desired in training or operational systems.

THE INTEGRATION OF SPATIAL INFORMATION FROM SHADING, TEXTURE GRADIENTS AND SURFACE CONTOURS

NR 196-189
University of Oregon/Stevens & Beck

Scientific Objectives: To understand the principal strategies by which spatial information from multiple, substantially independent, visual "cues" is integrated into coherent internal representations. The spatial information is of several different types (e.g., distance, local surface curvature), and the precision and accuracy of each varies according to the viewing conditions.

Approach: There are two parallel efforts: computational modelling and visual psychophysics. Two central computational problems are: conversion of spatial information across type and integration of information of each type which differs in precision or accuracy. Reaction time and masked tachistoscopic presentation are used to explore the time course of spatial judgments, and to determine which types of information are explicitly available in human vision. Functional coupling between representations will then be examined by bringing into opposition spatial information contributed from different sources.

Progress: Over the past year the apparent depth in monocular images in both perspective and orthographic projection has been examined by means of a computer-controlled stereoscopic probe. The first goal was to determine to what degree images that are specifically constructed to contain information about local surface orientation (but no depth information per se) give rise to a measurable variation in apparent depth. For comparison, stimuli were also examined in which perspective (producing a texture gradient or linear perspective effect) gave clear information about distance variation across the surface. The results in terms of apparent depth, while less in the orthographic images than in the perspective, demonstrated clearly that the visual system can transform surface orientation to distance information. Studies are underway on (1) how distance information is two-dimensionally extrapolated from locations where surface-orientation information is presented, (2) how depth from stereo disparity is made comparable to monocularly-derived depth, (3) the quantitative nature of monocularly-derived depth, and how relative depth is converted to absolute depth, and (4) computational models for surface interpolation in light of experimental findings regarding surface extrapolation.

Potential Applications: An application area is flight simulation, where spatial information from motion, stereopsis, texture, shading, surface contours and so forth are often of differing validity and even brought into opposition. Understanding of the type and magnitude of functional interaction among these sources of information will have application to simulator design.

INFERRING 3-D SHAPE FROM IMAGE MOTION AND OCCLUDING CONTOURS
NR 196-194
University of California, Irvine/Hoffman

Scientific Objectives: (1) To develop a formal theory of the recovery of three-dimensional shape from image motion and occluding contours; (2) to test the theory for psychological relevance using psychophysical experiments; (3) to develop a computer implementation of the theory.

Approach: The recovery of three-dimensional structure from images is viewed as fundamentally a process of inference. The premises of the inference are the image data, e.g., two-dimensional image motion or the two-dimensional projections of the folds of visible objects. The conclusion of the inference is a description of the three-dimensional shape of the viewed object. Perceptual inferences are in general not deductively valid, i.e., the conclusion is not logically guaranteed by the premises. Therefore, real-world constraints are determined which grant the inferences a fair degree of inductive strength. Precise statements are sought of what image information is sufficient, in conjunction with the constraints, to minimize false interpretations. These statements are given mathematical proof. Psychophysical predictions that arise from the formal theory of the perceptual inference are tested experimentally.

Progress: The constraints of fixed-axis rigid motion and fixed-axis rigid motion with constant angular velocity have been considered for the recovery of three-dimensional structure from motion. Three orthographic views of three points are sufficient to recover the correct three-dimensional structure using fixed-axis motion, and four views of two points were sufficient in the case of constant angular velocity. We are now testing subjects to see which of these constraints, if any, is being used by the human visual system. It appears that constant angular velocity is not required by the human visual system for the recovery of three-dimensional structure.

A formal definition of an observer was abstracted from the specific visual inferences studied. This definition of an observer plays the same role for the study of perceptual inferences that the definition of a Turing machine plays for the study of computation. This formal definition of an observer is used to study perceptual inferences abstractly while concurrently studying the specific visual inferences.

Potential Applications: This research will provide knowledge useful for the construction of automatic vision systems. It will also provide knowledge about the human perception of three-dimensional shape which is of value in the optimization of the man-machine interface. Finally, the definition of an observer will allow the study of perceptual inferences without distraction by details of specific inferences, and could be of value in advancing theories of physics which make an essential appeal to the notion of an observer, e.g. quantum theory.

INFORMATION PROCESSING IN PRIMATE VISUAL CORTEX
NR 197-083
California Institute of Technology/Van Essen

Scientific Objectives: Higher visual functions are carried out by a mosaic of cortical visual areas in the occipital, temporal, and parietal lobes. The objectives are to understand how information is processed within individual areas and how it is distributed through a hierarchy of areas via several functionally distinct streams.

Approach: Three experimental approaches are used for the analysis of visual cortex in monkeys and rats. The first involves the use of computer graphic displays for determining the responses of single neurons to texture patterns of precisely specified content. The second uses a new optical technique for monitoring neural activity simultaneously at many different sites across the surface of the brain. The third uses computer graphics to generate two-dimensional and three-dimensional representations of the cortical surface, for use in identifying visual areas and tracing their interconnections.

Progress: Studies on the neural basis of texture discrimination, done in collaboration with Bela Julesz, have yielded promising preliminary results. Recordings in visual area V2 of the macaque monkey, have encountered cells whose responses appear to encode local texture differences of a type that are pre-attentively discriminable to human subjects. Multi-channel optical monitoring led to the establishment of a new experimental setup. These initial phases are now completed, and preliminary recording experiments have been successfully carried out. The computer anatomy project has resulted in the first computer-generated two-dimensional maps of highly convoluted regions of the cortical surface.

Potential Applications: These studies will help to bridge the large gap between our understanding of human vision, based mainly on psychophysical experiments, and our much more detailed knowledge of visual processing in non-human primates. A more thorough understanding of the neural mechanisms underlying pattern recognition, motion analysis, and the control of directed visual attention will lead to better design of visual displays in training and operational equipment as well as a more effective use of the visual modality in robotics and image-processing applications.

A MULTI-LEVEL COMPUTATIONAL THEORY OF STEREOSCOPIC VISUAL IMAGE PROCESSING
NR 197-084
Naval Ocean Systems Center-Hawaii/Uttal

Scientific Objectives: The understanding of the rules and perceptual processes activated in the visual perception of stimulus forms in noise is to be determined for two and three-dimensional displays. The aspects of the stimulus which influence perception, the development of a mathematical model, and its refinement are to be pursued in that sequence.

Approach: Dynamic visual signals are presented on the surface of a dot-plotting oscilloscope under the control of a hybrid digital-analog computer. Psychophysical experiments are carried out to determine the relative detectability, discriminability, recognizability, and reconstructability (in noisy visual contexts) of various forms with changing dimensions of space and time. The geometrical form of the target varies as well as the microstructure of arrangement of dots that compose it. The major procedural innovations are the complete automaticity of the entire experimental procedure from the generation of stimuli to the production of graphic displays of the data and the interplay between the psychophysical results and the computational model.

Progress: A large number of the geometric parameters of the stimulus forms are varied to determine the effect of shape on detection, discrimination, recognition, and reconstruction. Among many other results, three novel and general rules of display perception are emerging: (1) Straight lines are the most powerful stimuli in complex displays and are easily detected; (2) Humans detect surfaces best when the surfaces are sampled with randomly-placed dots rather than with regularly-placed dots; and (3) Three-dimensional shape is not a strong determinant of detectability even though two-dimensional shape is. All three of these results are novel and unexpected; the first two are predicted by the correlational model that guides the research program. The third rule is not anticipated by the model and points the way to a new generation of computational models for these visual processes. These rules vary as a function of task (2D versus 3D) and sampling strategy.

Potential Applications: These perceptual processes are useful in understanding how to optimize the design of radar and sonar visual displays in both two and three dimensions; these perceptual processes are also salient in radiology, geology, atmospheric physics, and oceanography, where information must be extracted from noisy, grainy, and incomplete visual displays.

Reports

Uttal, W.R. (June, 1985). Test of a multi-level computational theory of stereoscopic visual image processing (Rep. PERILAB-6). Ann Arbor, MI: University of Michigan, Institute for Social Research. (AD A157011)

Kincaid, W.M., & Uttal, W.R. (1986). The effect of 3-D orientation and stretches on the detection of dotted planes. Perception & Psychophysics, 39, 392-396.

COMPUTATIONAL ANALYSIS OF THREE-DIMENSIONAL FORM
NR 197-088
Brandeis University/Todd

Scientific Objectives: The objective is to develop a data base of psychophysical functions between stimulus variables and perceptual judgments as foundations for the computational analysis of human vision. The research is directed at understanding how human observers infer 3-dimensional structure of objects in space from the patterns of light intensity within a visual image.

Approach: The investigator is developing a library of systematically controlled computer generated images with texture, shape, size, shading, reflectance and illumination. Psychophysical experiments are conducted that relate stimulus variations to judgments of orientation, depth and Gaussian curvature.

Progress: Five separate experiments, which investigated the effects of optical texture and perspective, have been completed. The data from these experiments were evaluated in terms of various computational models that have been proposed in the literature. A close fit of the data was obtained by adapting a neural network model of 2-dimensional perceptual organization recently proposed by Grossberg and Mingola. An extension of that model to 3-dimensional form perception suggested a number of quantitative predictions which were confirmed in subsequent experiments. Work has started on the perceptual analysis of image shading. One important finding that has emerged from pilot investigations is that abrupt changes in image intensity that occur at self-occluding boundaries are of fundamental importance for correctly interpreting smooth variations of intensity in neighboring regions. A new experiment is in progess to provide an empirical demonstration of this phenomenon. Observers' judgments of local surface orientation are obtained for identical regions of smoothly varying image shading in different contexts, both with and without self-occluding contours.

Potential Applications: Two aspects of this research make it particularly relevant to a number of practical applications. First, the relative perceptual salience of a wide variety of image properties will provide useful human factors guidelines for the generation of computer graphics displays. Second, comparing the abilities and limitations of actual human observers with those of existing computational analyses will suggest new directions for the analysis of visual information that may be useful to researchers in the field of machine vision.

Funding: NSF, ONR.

STUDY OF HUMAN VISION USING CELLULAR AUTOMATA
NR 197-089
University of California, Berkeley/Glaser

Scientific Objectives: To develop a computational model of binocular stereo depth perception and of motion perception using the formalism of cellular automata and parallel distributed processing networks. These techniques are readily simulatable on standard computers and have the possibility of working in real time on future parallel computers. They seem particularly well suited to capturing the main features of the neural architecture of the primate visual system and also to modeling at least some aspects of its performance.

Approach: Psychophysical results from the literature will be supplemented with new psychophysical experiments designed to help choose among possible visual mechanisms to be simulated. This work will use a variety of computer-driven CRT displays and occasional vision experiments not using CRT's. Particular attention will be given to distinguishing among local and global effects for which the psychophysics, the neural mechanisms, and the computational models may be quite different but related in some way. These models will use hierarchies of two-dimensional cellular automata or other parallel distributed-processing networks specialized in executing certain functions at each level with rich forward and retrograde communication among levels.

Progress: The investigators have shown that apparent depth of simple figures in the center of a field of view is strongly affected by simple stimuli quite far from the central region. Such global stereo effects have not been reported before. Vertical motion is strongly preferred over horizontal motion in certain ambiguous apparent-motion configurations. The first cellular automata models were not useful because they were not sufficiently constrained; almost any observed psychophysical result could be described well in many different ways. New constraints from anatomy and computational theory are being examined.

Potential Applications: Any computational model that successfully simulates a human psychophysical ability can serve a robot to do the same task. If the model uses cellular automata or other parallel distributed-processing techniques, there is a good possibility that a parallel computer can be built to perform at speeds comparable to or faster than human performance. Robots able to exhibit human performance at human or faster speeds will have many applications.

COMPUTATION OF STEREO AND VISUAL MOTION FROM BIOPHYSICS TO PSYCHOPHYSICS
NR SRO-202
Massachusetts Institute of Technology/Poggio, Hildreth & Koch

Scientific Objectives: To understand how the human visual system makes three-dimensional inferences from dynamic, two-dimensional retinal images. Specific areas of interest are the computations underlying the analysis of visual motion and binocular stereo.

Approach: The problems of binocular stereo vision and visual motion, and their fusion, are investigated through an interdisciplinary combination of computational theory and modelling, psychophysical experimentation, and neurophysiological analysis and experiments. This approach includes emphasis on: (1) the primitives for motion measurement and stereo matching; (2) the additional constraints needed to solve problems of measuring motion and stereo matching; (3) the detection of object boundaries from relative motion and depth; (4) recovery of 3D structure from motion and stereo and; (5) fusing stereo and motion information.

Recent theoretical developments in this research program suggest a common framework for most early vision problems and for the fusion of information from multiple visual sources.

Progress: Extensions of regularization theory have been exploited to develop algorithms for edge detection, spatiotemporal approximation, stereo and color computation. New structure-from-motion schemes have been analyzed and compared with psychophysical experiments. Hybrid networks of analog and digital components have been devised for efficient implementation of stochastic regularization algorithms for early vision problems. The biophysical basis of the computation of motion has been studied and experimental prediction has been perfected, together with powerful computer simulation tools.

Potential Applications: This research contributes to the understanding of (and possible improvement on) human performance in visual tasks. Interesting applications can be developed for processing visual images based on motion and stereo information, integrating results of different visual processes performed naturally or artificially, integrating information from different sensors, and achieving fast--possibly real-time--image understanding in machines.

Archival Report:

Poggio, T., Torre, V. & Koch, C. (1985). Computational vision and regularization theory. Nature, 317, 314-319.

IMAGE REPRESENTATION
NR SRO-203
New York University/Hummel & Landy

Scientific Objectives: The research seeks to enhance the understanding of human vision by studying data structures for image representation. The concentration is on variations of the Laplacian pyramid image-representation scheme, which decomposes image data into multiple scales of resolution. Methods for labeling information in image representations are also investigated in this study. The goal is to develop inference methods that can combine information from multiple data sources. Ultimately, this research seeks to aid computer vision systems in object recognition and scene analysis in the presence of ambiguity and noise.

Approach: By writing computer models of representation schemes, digital image data are transformed according to models of early visual representation. Three methods are used to study the validity of the representation. First, a mathematical analysis is made to determine the kind of information that is retained in the data structure, and how that information can be used to reconstruct an approximation to the original image. Second, by numerically computing such reconstructions, human observers in psychophysical experiments visually compare original data with reconstructed data, to assess the representation's ability to capture salient information in the image. Finally, methods for extracting features and inferring structure using the representation are studied. A successful representation makes explicit those features necessary for aggregating knowledge to interpret the image.

Progress: Attention has focused on Laplacian pyramid data-structure variants, and on iterative knowledge aggregation methods for inferring information from various sources. Progress has been made on multi-resolution decomposition of image data based on orientation-specific features. Nonlinear decomposition methods have been implemented. Among iterative inference methods, the Dempster/Shafer theory of evidence has supplied new ideas for representing degrees of uncertainty, resulting in novel combination formulas. A new iterative multi-resolution model of stereopsis computation has also been developed, incorporating those ideas on "spread of uncertainty."

Potential Applications: Knowledge of the human visual representation promises to aid image understanding tasks when building robotic systems capable of machine vision. More generally, methods for inferring structure and combining information should find applications in expert systems and intelligent computer devices.

Reports:

Hummel, R.A. (September 1985). Connected component labeling in image processing with MIMD architectures (Robotics Research Rep. 49) New York: New York University, Courant Institute of Mathematical Sciences.

Hummel, R.A. & Landy, M.S. (November 1985) A viewpoint on the theory of evidence, (Robotics Research Rep. 57) New York: New York University, Courant Institute of Mathematical Sciences.

Landy, M.S. & Hummel, R.A. (September 1985) A brief survey of knowledge aggregation methods, Rep. 51; New York: New York University, Courant Institute of Mathematical Sciences.

Archival Publications:

Carrihill, B., & Hummel, R. A. (1985). Experiments with the intensity ratio depth sensors, Computer Vision, Graphics, and Image Processing, 32, 337-358.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

DISCRIMINABILITY OF SIGNALS FROM NOISE IN A DYNAMIC STEREOSCOPIC SPACE
NR 197-070
University of Michigan/Uttal

Scientific Objectives: An analysis of visual detection sought an understanding of the relative importance of the global geometry of forms when the local features of the forms were carefully controlled. The autocorrelation model that adequately predicts psychophysical performance with 2-dimensional dotted patterns was utilized as a first approximation in the development of a figure of merit for the detection of 3-D dotted patterns and to predict the relative detectability of those forms.

Approach: The detection of forms composed of a constellation of dots within a background of random dots permitted the examination of subtle information-processing attributes of visual processes. Two dimensional targets (single dot, line, or plane) were embedded in random visual dots arrayed in 3-D space and experiments measured their detectability as a function of numerosity, position, repetitiveness, spacing, and orientation. The detection of single dotted lines was examined when they were masked by other dotted lines. The detection of various 3-D nonplanar forms composed of dots embedded in random visual dots was studied as a function of the spacing and density of the random dots, and the degree of deformation of the forms.

Results and Conclusions: Specific rules were defined for the perception of forms: (a) linear productivity - straight lines consisting of dots spaced equally from each other are detected better than when the dots are curved; (b) random sampling - response surfaces are detected better when they are constructed from random arrays of dots than from regular arrays when the regions near each other are more alike than their more distant regions; and (c) three-dimensional noncomputability - nonplanar surfaces, and presumably solid forms, cannot be processed by the visual system in the same way as two-dimensional objects; the nervous system does not seem to have the power to compute three-dimensional geometry.

Potential Applications: The use of dotted forms is a useful paradigm for the evaluation of designs of radar and sonar displays in both two and three-dimensional representations. The experimental results are suggestive for the design of informational displays in radiology, geology, atmospheric physics, and oceanography, where useful data must be extracted from noisy, grainy, and incomplete displays.

Report:

Uttal, W.R. (November, 1984). The discriminability of signals from noise in a dynamic stereoscopic space: Final Report (Tech. Rep. PERLAB-5). Ann Arbor, MI: University of Michigan, Institute for Social Research. (AD A148406)

C. DECISION MAKING

In the past ten years, research in human decision making has been trending away from comparisons of behavior with optimum economic or statistical models toward more descriptive, behavioral characterizations. Numerous robust behavioral phenomena have been identified which are more than simple, sub-optimal approximations of optimal models, but appear as contradictions, inconsistencies, fallacies and biases. These phenomena require explanation by psychological theory and the emphasis of research in this cluster is to implement this shift from behavior comparisons and description toward explanatory theory. Currently supported research includes the development of psychological theory in diagnostic inference processes, risk assessment and preference, selection of decision-choice heuristics, and reasoning processes in risky choice. The projects emphasize algebraic or production-system models of psychological processes that have the potential to account for behavioral phenomena.

EFFORT AND ACCURACY IN DECISIONS
NR 197-063
Duke University/Payne

Scientific Objectives: This research is directed at a better understanding of the psychological mechanisms that lead to the task-contingent use of decision strategies. The major hypothesis is that strategy selection is a function of a strategy's ability to produce an effective response and demand for mental resources or effort.

Approach: A number of the heuristic decision strategies are decomposed into a set of common elementary information processes (eips), such as comparing the magnitudes of two quantities. The eips are similar to those found in a variety of cognitive activities. Production system models of the heuristics are constructed. Monte-Carlo simulation is used to examine the effort and accuracy implications of the modeled heuristics in a variety of choice environments. Empirical validation of the models is conducted using the process-tracing techniques of verbal protocols, monitoring of information acquisition, and response-time measurement.

Progress: Initial efforts were directed at showing the impact of context and task variables on decision behavior. More recently, an extensive Monte-Carlo simulation of choice heuristics for both risky and nonrisky decision tasks was completed. The simulation showed that certain decision strategies approximated the accuracy of optimal procedures with substantial savings in effort. Effort and accuracy, however, were highly contingent upon characteristics of the task environment, such as number of alternatives and the presence or absence of dominated alternatives. An empirical study designed to test the validity of the decomposition approach to modeling decision heuristics, and to provide estimates of the effort associated with different eips, was completed. The study employed response-time measurement and a new computer-controlled methodology for monitoring information acquisition behavior. The results indicated that the total time to make a decision using a specified strategy was highly predictable from counts of the eips. Additional experiments to validate the model of the effort and the accuracy of choice heuristics are underway.

Potential Applications: The importance of task variables in the design of decision support systems is clear. The decomposition of strategies into sets of component elementary information processes, the computer simulation of production systems models, and process tracing experiments, will contribute to the design of more effective decision aids.

Archival Publications:

Johnson, E.J. & Payne, J.W. (1985). Effort and accuracy in choice. Management Science, 31, 395-414.

Laughhunn, D.J., & Payne, J.W. (1984). The impact of sunk outcomes on risky choice behavior. INFOR (Canadian Journal of Operational Research and Information Processing), 22, 151-181.

Payne, J.W. (1985). In G. Wright (Ed.), Psychology of risky decisions in behavioral decision making. New York: Plenum Press.

Payne, J.W., Laughhunn, D.J., & Crum, R. (1984). Multiattribute risky choice behavior: The editing of complex prospects. Management Science, 30, 1350-1361.

COGNITIVE CONTINUUM THEORY OF HUMAN JUDGMENT
NR 197-073
University of Colorado/Hammond

Scientific Objectives: The principal research objective is to compare directly the relative efficacy of three modes of cognition: intuition, quasi-rationality, and analysis, as they are actually employed in different task conditions.

Approach: Twenty-one expert highway engineers were studied over three different tasks, each displayed in three different ways. Indices were developed for (a) measuring the location of each task condition on a continuum ranging from intuition-inducing to analysis-inducing, and for (b) measuring the location of each expert's cognition on a continuum ranging from intuition to analysis. A new experimental methodology, namely a combination of Campbell and Fiske's multitrait, multimethod matrix and Brunswik's representative design, was employed in order to evaluate the convergent and discriminant validity of each judgment under each condition.

Progress: Individual analyses of each expert's performance over the nine conditions show that task-induced cognition is located at approximately the same location on the cognitive continuum index for virtually every engineer. In contrast to the results found with the customary indirect comparisons, intuitive and quasi-rational cognition frequently outperformed analytical cognition in terms of empirical accuracy. Analytical cognition produced infrequent but large errors. Judgmental accuracy was related in part to the degree of correspondence between the task location and the location of the expert's cognitive activity on the cognitive continuum. The methodology introduced in this study provides a new procedure for evaluating expert judgment.

Potential Applications: The task continuum index can be used to measure the extent to which judgment of decision tasks induce intuition or analysis, thus guiding the choice of cognitive support systems. The procedure developed for measuring convergent and discriminant validity of judgments can be generally used for evaluation of, and location of faults in, expert judgment.

Report:

Hamm, R.M. (1985). Moment by moment variation in the cognitive activity of experts (Tech. Rep. No. 257). Boulder CO: University of Colorado, Center for Research on Judgment and Policy. (AD A159466)

STUDIES IN RISK: PERCEPTION AND PREFERENCE
NR 197-079
University of Wisconsin/Lopes

Scientific Objectives: The theory to be tested proposes that perception of risk is related to the cumulative properties of risky distributions, with judgments of riskiness reflecting enhanced weighting of the worst outcomes in the distribution. Risk aversion is proposed to reflect a trade-off between avoiding risk and achieving some aspiration level.

Approach: Six experiments concerning participant preferences for risky distributions are related to the theoretical model and to self-reports of short-term and long-term goals and strategies. The planned experiments are: (1) a study of aspiration level effects among risk-seeking and risk-averse (RA) participants; (2) a comparison of distributional preferences for potential gains and losses; (3) a comparison of risk preferences for monetary and non-monetary situations; (4) a study of risk attitudes under offensive and defensive sets in a competitive task; (5) an exploratory study of process-tracing techniques in risk processing; and (6) an exploratory study of a mathematical index for quantifying riskiness.

Progress: The main results of Experiment 1 were (1) that reflection occurs reliably for both risk-averse and risk-seeking participants only when one of the gambles in the choice pair involves a riskless component (or, for RA participants, a sure thing), and (2) patterns of preferences for risk-averse and risk-seeking participants are not suggestive of pure risk styles, although the patterns are largely antithetical to one another. Instead, the data suggest that the two groups differ in their goals and their strategies for satisfying competing needs. Analysis of protocol data from Experiment 5 suggested that risk-aversion and risk-seeking attitudes reflect primarily (1) aspiration-level effects for all participants and (2) security seeking for risk-averse participants versus potential-seeking for risk-seeking participants. The primary result of Experiment 3 was that participant preferences for distributions are quite similar for monetary and non-monetary scenarios, although differences in goals produced some shifts of preference. Data collection in progress for Experiment 4 suggests that, in competitive tasks, preferences among moves differing in the distribution of possible outcomes will be determined primarily by current needs (i.e., board position) rather than by simple aversion or attraction to risk. Theoretical work is progressing on a model of risk embodying the effects of aspiration level and security/potential motivation. The model is intended to include an index of distributional security/potential (Experiment 6).

Potential Applications : General understanding of risk perception and processing may contribute to being better able to predict and understand behavior under risk in real situations. Psychological assessment of risk attitude may contribute to the selection of personnel for risky operations and for training of personnel who must operate under risk.

Report:

Schneider, L. & Lopes, L. L. (1985). Reflection in preferences for multioutcome lotteries (Tech. Rep. WHIPP 22). Madison, WI: University of Wisconsin, Human Information Processing Program. (AD A157232)

PROBABLE CAUSE: A DECISION MAKING FRAMEWORK
NR 197-080
University of Chicago/Einhorn & Hogarth

Scientific Objectives: Causal inference is an essential cognitive activity that combines judgments of causation with judgments under uncertainty. Thus, causal inference involves judgments of probable cause. Since uncertainty and causality are intertwined in most real-world situations, the goal is to understand how, and how well, people combine these two modes of thought.

Approach: A model is developed for understanding how judgments of probable cause are formed. The model consists of three major elements: (1) the causal strength of a variable is first shown to depend on its being a deviation or difference in a background or field (much like a figure/ground relation); (2) various cues-to-causality, such as covariation, temporal order, contiguity in time and space, and similarity of cause and effect, are discussed as probabilistic indicators of causal relation. A model for combining the cues and background is developed that captures many aspects of causal inference; and (3) the discounting of the strength of an explanation on the basis of specific alternatives is considered as a special case of the sequential updating of beliefs.

Progress: The model for evaluating the strength of a causal explanation accounts for many interesting and heretofore diverse aspects of causal and statistical inference. For example, the concepts of "spurious correlation", "illusory correlation", confusion of inverse probabilities, confusion of joint and conditional probabilities, violations of the conjunction rule for the probability of two events, and so on, are brought under one conceptual approach. Furthermore, the model can be extended to more complex issues having to do with scenario coherence, types of causal chains, and the use of imagination in constructing causal explanations.

Potential Applications: This work can be applied to any decision-making context where incomplete and uncertain evidence must be evaluated with respect to causal implications.

Reports:

Einhorn, H. J. (1985). A model of the conjunction fallacy (Tech. Report). Chicago, IL: The University of Chicago.

Einhorn, H. J., & Hogarth, R. M. (1985). A contrast/surprise model for updating beliefs (Tech. Report). Chicago, IL: The University of Chicago.

Hogarth, R. M. (1985). Why bother with experiments? (Tech. Report). Chicago, IL: The University of Chicago

Hogarth, R. M. & Kunreuther, H. (1985). Risk, ambiguity, and insurance (Tech. Report). Chicago, IL: The University of Chicago

Archival Publications:

Einhorn, H. J., & Hogarth, R. M. (1985). Ambiguity and uncertainty in probabilistic inference. Psychological Review, 92, 433-461.

Einhorn, H. J., & Hogarth, R. M. (1986). Judging probable cause. Psychological Bulletin, 99, 3-19.

Hogarth, R. M. & Kunreuther, H. (1985). Ambiguity and insurance decisions. American Economic Review, (AEA Papers and Proceedings), 75, 386-390.

DECISION AND JUDGMENT
NR 197-081
Stanford University/Tversky & Kahneman

Scientific Objectives: The development of a descriptive analysis of judgment previous work on judgment under uncertainty and prospect theory.

Approach: The traditional approach to the study of decision making has been normative in character and structural in form. That is, it derives from rational or logical analysis of decision and judgment, and it characterizes the structure of preferences and beliefs. In contrast, here a descriptive approach is adopted that is constructive in nature. This approach attempts to account for the manner in which people construct judgments and decisions. Because the act of constructing preferences and beliefs depends on the manner in which the problem is framed, the invariance condition that characterizes structural theories does not always hold.

Progress: (1) Analysis of transparent and opaque decision problems: A systematic empirical analysis of risky choice reveals that human decisions violate not only the strong conditions of cancellation (or independence) and transitivity; they also violate the most basic conditions of (stochastic) dominance and invariance. Because the latter are essential to any so-called rational model, the discrepancy between the normative and the descriptive analyses cannot be reconciled. On the other hand, the same axioms are generally satisfied in transparent situations; i.e., problems that are framed so that the applicability of the axioms is clear. (2) Multiattribute prospect theory: An analysis of different choice structures has been developed: (a) positive choices between two goods, or between a monetary gain and a good; (b) the "goods-money exchange" in which a good is given up in exchange for money; (c) negative choice between two losses or otherwise aversive consequences; (d) the "money-goods exchange" in which money is given up in exchange for a good. The comparison of (b) and (d) provides a sensitive measure of loss aversion (the typical manifestation of loss aversion is a general reluctance to trade). The comparison of structures (a) and (c) provides a measure of relative loss aversion. We have confirmed loss aversion and assessed relative loss aversion for a number of different attributes. The pattern of results is robust, indicating very extreme loss aversion for increases in risks (e.g., safety or health), and rather little loss aversion for leisure (e.g., vacation days) relative to money. (3) Designs for probability judgment: theories of subjective probability are viewed as formal languages for analyzing evidence and expressing degree of belief. Two probability languages, the Bayesian language and the language of belief functions, were analyzed from that perspective. A comparison of the semantics (i.e., the meaning of the scale) and the syntax (i.e., the formal calculus) of these languages suggests different approaches to probability judgment. The concept of a design for judgment of probability, analogous to the notion of the design of an experiment, is developed and applied to a few evidential problems.

Potential Applications: The role of framing, the distinction between transparent and opaque problems, the analysis of loss aversion, and the concept of design for probability judgments all provide descriptive and analytic tools for evaluating and debugging human judgment and decison making.

Funding : ONR, AFOSR.

Archival Publications:

Shafer, G. & Tversky, A. (1985). Languages and designs for probability judgment. Cognitive Science, 9, 309-339.

Tversky, A. & Kahneman, D. (1984). The framing of decisions. Covello et al. (Eds.), ASI Series, Vol. G4, NATO.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

TASK INFLUENCES IN THE ANALYTIC-INTUITIVE APPROACH TO DECISION MAKING
NR 197-074
Rice University/Howell

Scientific Objectives: Experiments sought to determine the effects of task variables on human judgment and decision behavior. Variables were chosen and consequences predicted largely on the basis of Hammond's cognitive continuum theory, using tasks designed to be neither exclusively "intuition-inducing" nor "analysis-inducing".

Approach: Experiments are conducted in a variety of problem contexts. The emergency resource allocation problem required acquisition and use of observed event-frequency patterns. The optional stopping problem involved a succession of choices between drawing more information and taking terminal action. The personnel decision and threat evaluation problems were multiple cue-weighting tasks of the sort used in "policy-capturing" research. The two-stage judgment task permitted the study of cue-weighting strategies as a function of various levels (and kinds) of input pre-processing.

Results and Conclusions : Findings were fairly consistent with Hammond's theory, although the research was not intended as a direct test of that model. More importantly, a number of task features were shown to influence judgment/ decision performance reliably--in some cases, across task scenarios; in others, in a selective fashion. For example: judgment was affected in both qualitative and quantitative ways by the manner in which information was displayed. Graphic coding promoted more "holistic" processing than did numeric coding, and consequently, better decisions under "pressure" situations. Time pressure, amount of information, rule availability, and rule complexity did not produce the "across the board" effects suggested by continuum theory. Each affected some aspect of performance on some task scenario, but not in the coherent fashion one would expect if an individual's cognitive approach were merely shifted along a continuum.

Potential Applications: Care should be taken in choosing the features of decision systems (such as display formatting, task sequencing, highlighting, feedback mode), since these can and do affect many aspects of the decision process. Graphic coding is particularly useful where conditions dictate "intuitive" judgment. Manual preprocessing is a promising alternative to aiding in some decision settings.

Reports:

Fontenelle, G. & Howell, W. C. (1985). A replication and extension of the inducement of the availability heuristic (Tech. Rep. No. 84-5). Houston, TX: Rice University, Dept. of Psychology, December, 1985.

Friedman, L., Howell, W.C., & Jensen, C.R. (1984). Diagnostic judgment as a function of the preprocessing of evidence (Tech. Rep. No. 84-4). Houston, TX: Rice University, Dept. of Psychology, October, 1984.

Howell, W. C. (1985). Task influences in the analytic intuitive approach to decision making (Final Report). Houston, TX: Rice University, Dept. of Psychology, December, 1984.

D. DISTRIBUTED TACTICAL DECISION MAKING

This is a Special Focus Program sponsored jointly by ONR and the Space and Naval Warfare Systems Command (SPAWARS). It is a multidisciplinary research effort involving psychological, mathematical, computer science and communications approaches to basic issues in multi-person, cooperative decision making. The program is intended to provide scientific underpinnings in the form of theories, models, methods and functional relationships among key variables which define decision making in geographically dispersed, decentralized command/control systems. Initial research topics of concern include strategies for decomposing complex problems that lead to effective organizational architectures, strategies for aggregating multi-person judgments, estimates and plans leading to effective consensus, and strategies for maintaining data-base concurrency in dynamic, multi-operator environments. The program emphasizes measures of effectiveness for distributed decision systems with special attention to the issues of reconfiguration and reconstitution.

RESEARCH IN DISTRIBUTED DECISION MAKING WITH APPLICATIONS TO C^3 SYSTEMS DESIGN

NR 649-001
Alphatech, Inc. & University of Connecticut/Castanon, Entin, Serfaty, & Kleinman

Scientific Objectives: The objective is to develop contributions to an integrated theory of distributed tactical decision making based on theoretical and experimental research in mathematics and psychology.

Approach: The work will consist of two major tasks. The first task will develop mathematical models in team and game theory with emphasis on developing quantitative methodologies for analyzing problems of dynamic decision making under uncertainty. Under this task, team decision problems will be investigated as distributed optimal stopping problems and dynamic stochastic games. Conditions characterizing optimal team strategies and performance in these decision problems will be investigated. The second task will focus on the development of normative/descriptive models of human decision making. This task will build on theories and models of behavioral decision making.

Progress: The mathematics component of the research program has focused on decision algorithms for finite-state, discrete-time, partially observable Markov decision processes, characterized by uncertainty in the state due to noisy measurements. The basic algorithm is stochastic dynamic programming which: (a) involves the temporal decomposition of a dynamic problem into a sequence of static problems; and (b) separates estimation and control functions. The Smallwood-Sandik formulation is being used in the development of decentralized control models. The human factors research has produced a testbed and experimental designs for investigating multi-person information processing and decision making. The principal independent variables are: team structure (hierarchical and parallel); information and communication networks (decentralized, centralized and partially overlapping) and levels of expertise. This component of the program seeks to test and refine the normative mathematical models. Pilot studies have been conducted in preparation for a series of experiments that will test normative models for information processing and resource allocation functions.

Report:

Castanon, D.A., Entin, E.E. & Kleinman, D.L. (1985). Research in distributed decision making, Annual Summary Report, Alphatech, Inc. Burlington, MA.

Archival Publications:

Castanon, D.A., Chang, S.C, Luh, P.B., & Wu, Z.J. (1985). Optimal task allocation for a team of two decision makers with three classes of impatient tasks, 8th MIT/ONR Workshop on C3 systems, Cambridge, MA.

Serfaty, D. and Kleinman, D.L. (1985). Distributing information and decisions in a team, Proceedings of the IEEE Conference on Systems, Man and Cybernetics, Tucson, AZ.

DISTRIBUTED TACTICAL DECISION MAKING
NR 649-003
Massachusetts Institute of Technology/Athans & Levis

Scientific Objectives: The objective of the research is to address theoretical and computational issues that arise in the modeling and analysis of distributed tactical decision making. The research plan has been organized into two highly interrelated research areas: (a) distributed decision processes; and (b) distributed organizational structures.

Approach: Theoretical and experimental investigations are being conducted to develop: (a) models and algorithms for decision strategies of distributed agents with communications restrictions in situation assessment and resource allocation tasks and (b) models and methods for describing and evaluating alternative organizational structures including serial, parallel and multi-echelon structures.

Progress: To capture the interactive improvement in the solution of underlying optimization problems, recent models of individual decision making are being extended toward the development of goal decomposition models that define the role of the local decision maker, and the limits of his authority. A computational model referred to as the performance-workload locus, has been developed for evaluating alternative organizational structures. Models of asynchronous decision process protocols that define coordination points, concurrent operations and random task-completion times have been formulated using stochastic time Petri Nets.

Reports:

Tsitsiklis, J.N. (1984). Problems in decentralized decision making and computation Report LIDS-TH-1424, Laboratory for Information and Decision Systems, MIT, Cambridge, MA.

Bejjani, G.J. and Levis, A.H. (1985). Information storage and access in decisionmaking Organizations LIDS-P-1466, Laboratory for Information and Decision Systems, MIT, Cambridge, MA.

Boettcher, K.L. (1985). A methodology for the analysis and design of human information processing organizations, Rep LIDS-TH-1501, Laboratory for Information and Decision Systems, MIT, Cambridge, MA.

DECENTRALIZED RESOURCE MANAGEMENT IN TACTICAL COMPUTER EXECUTIVES
NR 649-004
Carnegie-Mellon University/Jensen

Scientific Objectives: This research addresses the problem of computer system configuration, i.e., the dynamic assignment and reassignment of data to processing nodes, at the level of the operating system which supports multi-person decision making.

Approach: The technical approach entails the development of: (a) concurrency control theory and mechanisms for decentralized resource management and scheduling; and (b) reconfiguration algorithms to meet changing operational demands. An important feature of the technical approach is to treat the decentralized operating system as a special form of a distributed data base. This calls for incorporating within the kernel of the operating system an atomic transaction facility. The approach taken is to supplant the traditional model of serialization transactions with transactions of greater concurrency and modularity.

Progress: A formal theory of modular concurrency control and failure recovery has been formulated. The theory is a generalization of classical serializability theory and failure atomicity. The rules of the theory provide for the consistency of shared data and allow transactions to be programmed, modified and scheduled independently of the rest of the transactions in the system. In addition, a hybrid system of fast algorithms have been developed for dynamic system reconfiguration; these algorithms operate in near real time and minimize the disturbance to the functioning tasks in the course of reconfiguration.

Report:

Jenson, E.D. (1985). Decentralized resource management in tactical computer executives, Annual Summary Report, Pittsburgh, PA. Carnegie-Mellon University, Department of Computer Science.

THEORY OF INFORMATION PRESENTATION FOR DISTRIBUTED DECISION MAKING
NR 649-005
Engineering Research Associates, Inc./Noble

Scientific Objectives: Formulate and test a theory of information presentation that embodies fundamental elements underlying the understanding and effective transfer of complex information among dispersed decision makers. The proposed theory focuses on the refinement and integration of schema as methods to improve the presentation and understanding of visually displayed information. Schema, as defined in this theory, are structures which enable situations to be classified and associated with appropriate action rules.

Approach: The theory predicts the relationship between the features emphasized in a situation display and people's assessments of different alternatives for that situation. The theory suggests how situation features should be tailored in order to promote consensus, and what information should be transmitted to effect a common situation understanding. The research tests the theory by varying situation display features and computing the covariance between measured and expected situation classifications, alternative assessments and decision conflicts.

Progress: Methods for constructing and representing schema in graphic and symbolic form have been developed. The essential characteristics of schema include: (a) slots for features that define a situation or object; (b) constraints that limit features to fill slots; and (c) inferences and actions which are appropriate if a schema is activated. Experiments are underway using schema representations of enemy fleet deployment scenarios to investigate how the level of threat is assessed as a function of the form in which information is presented.

Report:

Nobel, D.F. & Truelove, J.A. (1985). Schema-based theory of information presentation for distributed decision making Tech Rep. R-028-85. Vienna, VA: Engineering Research Associates.

ACQUISITION AND REPRESENTATION OF KNOWLEDGE FOR DISTRIBUTED COMMAND DECISION AIDING
NR 686-001
Johns Hopkins University/Hamill & Stewart

Scientific Objective: Investigate critical factors underlying knowledge-based decision-aiding systems to support spatially separated tactical commanders in Navy command and control environments.

Approach: The research develops models and collects performance data which will contribute to a theory of distributed decision making. The research focuses on: (a) the acquisition of relevant knowledge from subject-matter experts; (b) the representation of knowledge (c) the utilization of knowledge in problem solving and decision tasks. Algorithmic and heuristic approaches are explored in the development of control structures for the representation of knowledge bases. Models of multi-person decision making are formulated and common structures in the decision process investigated. Measures of decision making will be developed and experiments conducted in command and control simulation facilities to verify the models and to investigate the features underlying knowledge-based systems.

Progress : A taxonomic structure has been developed to identify and organize distributed decision making. The taxonomy is constructed along the three dimensions of psychological, computational and communicative processes. Each dimension is defined in terms of acquisition, representation and utilization of knowledge. Work has been initiated on the classification and evaluation of knowledge representation formalisms, e.g., Franz Lisp, Interlisp-D, YAPS; important differences have been observed in capabilities to support semantic network structures and mulitiple rule sets.

Report:

Hamill, B. W. & Stewart, R. L. Acquisition and representation of knowledge for distributed command decision aiding. Annual Summary Report. Laurel, MD: Johns Hopkins University, Applied Physics Laboratory.

Archival Publication:

Hamill, B. W. (1984). Psychological issues in the design of expert systems (p: 73-77). In Proceedings of the Human Factors Society 28th Annual Meeting. Santa Monica, CA: The Human Factors Society.

MODELS OF GROUP DYNAMICS IN DISTRIBUTED TACTICAL DECISION MAKING
NR 686-003
PAR Technology Corp./Adelman & Lehner

Scientific Objectives: The objective is to conduct theoretical and experimental research on the psychological determinants of group decision making. The focus is on developing a psychological model that is applicable to decision environments with a flexi[illegible] reconfigurable command and control system in a multi-threat envi[illegible]

Approach: The proposed psychological model distinguishes between: (a) individual and group input factors; (b) characteristics of the group's interaction process; and (c) various outcome variables. Issues that are investigated within this model include: (1) the extent to which a division of responsibility is impacted by alternative communication networks and protocols; (2) the degree to which a cooperative vs. non-cooperative environment impacts distributed-team performance; and (3) the extent to which a common cognitive model of a decision problem in tactical situations is required for effective team performance.

Progress: A conceptual model has been developed that describes relationships and variables postulated as important mediators of group performances in distributed decision environments. The model derives primarily from research on communication networks, mental models and game theory. The principal mediators in this model are organizational structure affecting division of labor and resources, cognitive model similarity and consistency, and norms supporting group cooperation. Experimental designs have been developed and pilot studies conducted in preparation for a major experiment on resource allocation by distributed decision makers.

Archival Publication:

Adelman, L., Zirk, D. & Lehner, P.E. (1985). A conceptual framework for addressing group dynamics in distributed decision making. Proceedings of 1985 IEEE Conference on Systems, Man and Cybernetics.

BEHAVIORAL ASPECTS OF DISTRIBUTED DECISION-MAKING
NR 686-004
Perceptronics/Fischhoff & MacGregor

Scientific Objective: Develop a behaviorally-based theory of distributed tactical decision-making that extends existing research on individual decision-making into this realm.

Approach: Distributed decision systems have been characterized, initially, by the number of individuals or groups involved in a system or subsystem and, subsequently, by behaviorally significant features of the tasks facing those in the system. These features are drawn from cognitive psychology, behavioral decision theory, and organizational theory, and they include the uncertainty surrounding the decisions to be made, the clarity of the systems' overriding policy, and the heterogeneity of the participants in the system.

Progress: A theoretical framework was developed with the properties and realities of a variety of existing distributed decision-making systems in mind. It was extended to detailed analyses of several specific systems and the recurrent problems facing them. Analyses include: (1) the challenges faced by systems in avoiding "strategic surprises," wherein their shared model of reality becomes increasingly and profoundly out of touch; (2) the behavioral properties of the tasks; and (3) the role of systems whose nature may change markedly from their inception to their operation. A medium fidelity simulation of a distributed decision-making system will investigate at least two issues: how broadly-stated principles of system philosophy are interpreted in specific situations and how the distribution of information within a system influences the shared model(s) held by the system participants.

DISTRIBUTED ROBUST COMMUNICATION CONTROL
NR 662-004
University of Maryland/Ephremides and Makowski

Scientific Objectives: To investigate and develop algorithms for radio communication networks that can be implemented in a distributed fashion, for the purpose of ultimately integrating the communication issues in the distributed tactical decision-making command-and-control framework.

Approach: A dual approach of analytical study and algorithm development is pursued. An analysis focuses on performance evaluation of communication protocols in realistic multihop networks with variable topology and on adaptive control procedures for routing and resource allocation as well as on distributed detection/estimation issues associated with the operation of such networks. The algorithm development emphasizes the practical specification of intelligent heuristics for network connectivity establishment, maintenance, and utilization, that posses good performance attributes in terms of survivability, effectiveness, and efficiency. Both approaches consider the use of spread-spectrum signaling that imposes new constraints while at the same time opening up new degrees of freedom in the communication control process.

Progress: The notion of system dominance was shown to be a powerful tool for studying the performance of non-standard queueing systems which naturally arise in the modelling of various communication functions. The methodology was successfully applied to systems with synchronization constraints, such as the Fork-Join queue, where computable bounds and approximations were obtained for various statistics of the system response time, both in transient and steady-state. A similar approach was taken in the study of interacting queues modelling ALOHA-like contention systems. Here, simpler bounding systems were identified and stability regions for the original system were determined.

Report:

Ephremides, A. & Makowski A.M. (1985). Distributed robust control in radio networks, Annual Summary Report. College Park, MD.: University of Maryland, Department of Electrical Engineering.

E. SPECIAL PROJECTS

Man-Machine Systems Technology

This Exploratory Development (6.2) project is designed to extend the basic research program in Engineering Psychology toward applications in Navy man-machine systems. Currently the project consists of applied research in three topic areas: decision making in command and control systems; human-factors design for maintainability; and supervisory control. In the command-and-control area, the various work units are investigating information processing and decision performance in Naval mission planning, airborne ASW, submarine combat control, and surface ASW. In the maintenance area, efforts are directed toward the development of analytical techniques and models of technician performance which can be used to predict the maintainability of equipments as a consequence of design characteristics. The work on supervisory control is exploring the application of new interactive control concepts to underwater vehicles and remote manipulators.

Defense Small Business Advanced Technology Program (DESAT)

The objectives of the DESAT program include stimulating technological innovation to the private sector, strengthening the role of small business in meeting the DoD research and development needs, and increasing the commercial application of DoD-supported research and development results.

The research conducted by Intelligent Software Systems, Inc. (NR DSA-009) has as its goal the design, assembly, test, and demonstration of a prototype graphics workstation for real-time analysis and extraction of information from large data bases. The system will have the capability to generate a large set of graphic formats while the user will have the capacity to choose a preferred format from a data base and to monitor and detect a set of events in a dynamic data-base. These demonstrations will explore a wide range of display preferences by a representative group of users for different tasks pertaining to process control. The second research effort, conducted by Decision Science Consortium, Inc. (NR DSA-010), has as its objective the design, assembly, test, and demonstration of a prototype system for a personalized and prescriptive decision aiding system. This system will accommodate to individual differences in preferred levels of problem analysis, information search organization, decision rules, and display features. The task addressed will be a personnel allocation decision problem.

MODELING HUMAN DECISION PROCESSES IN COMMAND AND CONTROL

NR 460-001
Alphatech, Inc./Wohl

Scientific Objectives: To develop quantitative models of human decision processes in ASW command and control functions.

Approach: The approach involves the development of normative-descriptive models based on the Stimulus-Hypothesis-Option-Response (SHOR) paradigm. The decision functions of the antisubmarine warfare commander (ASWC) have been selected as the context for model development. The total ASW simulation is comprised of two components: a model of the ASW environment and an ASWC tactical decision model. The environmental model simulates the dynamics and operational characteristics of the ASW platforms, ASW sensors, and enemy submarines. It outputs the sensor data and the own-force platform states to the ASWC model. The ASWC model consists of two submodels: (1) a model that represents the ASWC's hypothesis generation and evaluation procedure (situation assessor); and (2) a model that represents the ASWC's option evaluation procedure (resource manager).

Progress: Data encoding and computer programming have been completed. Representative inputs to the model include: ASW force composition and operational capabilities, likelihood functions for sensor probability of detection, enemy submarine trajectories and cognitive style of the commander. The model outputs a time series of commands issued by the ASWC related to the management of his resources and also provides a number of performance measures, such as time between initial contact and prosecution and percentage of contacts localized. Experiments are underway to validate the situation assessment module.

Potential Applications: These models of human decision processes have potential for application in the following areas: (1) methodological tool for design of C^2 systems; (2) modelling basis for the development of decision aids for situation assessment; and (3) simulation methods and models for ASW tactical training devices.

HUMAN FACTORS PRINCIPLES FOR SUBMARINE TACTICAL DECISION AIDING

NR 460-002
Decision Science Consortium, Inc/Cohen and Chinnis

Scientific Objectives: The generation and testing of human factors principles for the design of tactical decision aids based on theories and models of human decision making. A major objective is the determination of the forms of human-computer interaction which are most effective in guarding against human information-processing biases and limitations.

Approach: Experiments are conducted using a computer-based attack planning aid which has been implemented in the submarine combat simulation laboratory, NUSC, Newport. The experiments involve tests of hypotheses regarding cognitive mechanisms and factors that may influence decisions during a passive approach against a hostile submarine. These factors include: attentional selectivity with regard to risk to own ship, target importance, confidence in the process of integrating target range estimates, weighting critical probabilities (e.g., of counterdetection), attempting to eliminate uncertainties prior to decision, and framing (e.g., describing potential outcomes in terms of hits or misses). Decision aid features to address each of these factors are tested.

Progress: The investigators have developed computer-based interface functions which provide both prescriptive and descriptive constraints. These include: 1) PLANNING for data entry and query at various levels of specificity and aggregation; 2) SELECT EXPLANATION for an examination of inference rules and conclusions; 3) ADJUST for making changes in data values and previewing the impact of changes on subsequent events; 4) ALERT for prompting when thresholds are reached and/or new events occur; 5) ADVISORY for prompting when cognitive strategy may be suboptimal and/or when there is evidence of conflicting lines of reasoning.

Potential Applications: The testing of models of cognitive performance in a realistic setting with representative participants provides valuable insight into the validity of such models, as well as needed guidelines for the design of computer-based command and control systems.

Report:

Leddo, J. & Cohen, M. (1985). Experimental designs for research on submarine tactical decision aiding (Technical Memorandum). Falls Church, VA.: Decision Science Consortium.

HUMAN FACTORS IN EXPERT SYSTEMS
NR 460-009
Naval Ocean Systems Center/Allgaier

Scientific Objectives: This work unit focuses on human factors issues affecting the development and use of computer-based expert systems for Naval mission planning functions. It is part of an interdisciplinary effort directed at the development of human factors and computer science technologies for improved decision-support systems.

Approach: The human factors effort concentrates on four technology issues: (1) definition of functional requirements and development of decision-process models of mission planners; (2) reliable methods for knowledge elicitation and representation; (3) development of a man-machine interface and explanation facility; and (4) performance assessment. The air strike planning function was selected as the context for this work which included the development of an experimental expert-system for mission planning.

Progress: The underlying structure and principal components of the experimental expert-system have been defined. A task analysis and decision process model for air strike planning functions were developed with the assistance of operational personnel. Existing strike-planning decision aids were assessed with a view to identifying relevant heuristics and algorithms. Efforts are directed to the development of a module for planning weapons loading; subsequent work includes modules for weapons selection and route planning functions. Menu-based interface concepts, based on CMU-ZOG developments are explored and a Lisp object-oriented programming system was selected for investigations of methods for knowledge representation.

Potential Applications: The results of this work will contribute to the human factors and computer science technology base by providing improved methods and priniciples for use in the development of computer-based expert systems. These technological developments have the potential for significantly enhancing human decision performance in tactical planning functions.

Report:

Ehler, P, Osga, G., Lambert, D. & Cook, T. (1985). Expert systems in support of composite warfare commander mission planning (Tech. Rep. 1067). San Diego, CA: Naval Ocean Systems Center.

HUMAN FACTORS AFFECTING MAINTAINABILITY OF SHIPBOARD PROPULSION SYSTEMS
NR 503-001
Perceptronics, Inc./Madni

Scientific Objectives: (1) To develop improved methods for representing and analyzing complex maintenance tasks in shipboard propulsion systems; and (2) to develop and evaluate concepts and principles for the human-engineering design of equipments and maintenance support systems in order to improve the maintainability of shipboard propulsion systems.

Approach: A model-based approach for representing and analyzing maintenance tasks was developed. The approach involves modelling human actions, decisions, and responses to specific events within Modified Petri-net representations. Within the framework it was possible to: (a) identify procedural inconsistencies and ambiguities that impair human performance; (b) predict task-related workload; (c) develop guidelines for evaluating human-equipment interface options; and (d) determine where task reallocation was necessary and feasible. Operator tasks related to the maintainability of shipboard gas turbine propulsion systems were selected as the context for the modeling work which includes individual and cooperative tasks as well as multiple equipment malfunctions.

Progress: A knowledge-based task analysis framework using the Modified Petrinet model was developed to identify potential man-machine interface problems. Model-guided expert elicitation and model refinement was performed to explicitly encode contingency handling procedures. The model was implemented to exhibit dynamic task execution and on-line performance/workload predictions based on the elicited procedures and expert ratings. Key model elements were verified with data collected from gas turbine training simulation exercises.

Potential Applications: The modeling techniques and computer-aided analysis tools have the potential for identifying improved man-machine interface design options, task allocation, and high pay-off job-aiding functions.

COMPUTER-BASED MODELS FOR MAINTAINABILITY DESIGN
NR 503-003
University of Southern California/Towne

Scientific Objectives: The objective is to develop models for predicting equipment maintainability as a consequence of its internal structure and the design of the man-machine interface. A central feature of the work is the development of a computer-based model of maintenance-technician performance including fault diagnosis and repair.

Approach: A computer-based model referred to as PROFILE was developed for assessing the maintainability of a system. The model uses data representing the system's physical construction, internal organization and fault-effects. For each fault of interest, PROFILE generates a sequence of actions required to isolate and correct a malfunction, and it determines the time to perform the generated procedure by accessing a data bank of standard times for generic maintenance actions.

Progress: Detailed performance data derived from experiments were analyzed to determine the variables which affect the cognitive time to accomplish fault diagnosis. The PROFILE model was enlarged and refined, to project the cognitive component as well as the manual component of equipment maintenance. With this expansion, and the completion of the graphical interface to PROFILE, the system was tested for the accuracy and sensitivity of the technique, as well as the ease of use by design personnel.

Potential Applications: The model has application within the design cycle to aid the product engineering process. It can assist in evaluating the maintainability characteristics of completed design proposals. Researchers in human factors and design may employ the model to explore relationships between design and maintainability.

Report:

Towne, D. M. & Johnson, M. C. (1985). Cognitive workload and complexity in fault diagnosis (Tech. Rep. ONR-106). Los Angeles, CA: University of Southern California.

REMOTE CONTROL OF UNDERWATER VEHICLES AND MANIPULATORS
NR 512-001
Massachusetts Institute of Technology/Sheridan & Yoerger

Scientific Objectives: The objective of this work is to investigate man-machine features and control models for deep-ocean, remotely operated vehicles and manipulators. Computer-aided supervisory control techniques are being evaluated to improve operator performance and overall system capabilities through concurrent control of both the vehicle and the manipulators.

Approach: The approach taken combines engineering analysis, simulation, and experimentation. A task analysis is being performed based on operational experience in deep ocean tasks. Dynamic models of a vehicle and its manipulators are being used to evaluate alternative designs. New nonlinear control-theoretic techniques are being used to design a closed-loop control system that permits an advanced supervisory architecture to be implemented. Analysis and experiments in supervisory control techniques performed under related programs at MIT will be used as the basis for the overall control system design.

Progress: Basic functional requirements for the vehicle and manipulators have been established. Kinematic and dynamic models were formulated and a new nonlinear control technique developed using an approach appropriate to a wide range of vehicles. Simulation results showed the method can handle extreme nonlinearities; the method also contained interesting monitoring features that fit smoothly into a supervisory control scheme. Models for concurrent control of a vehicle and manipulators and the design of a new master controller are being investigated.

Potential Applications: The supervisory control concepts and models will have application to the design of advanced Navy underwater search-and-inspection vehicles.

PERSONALIZED INTERACTIVE DISPLAY AND ANALYSIS SYSTEM FOR INDIVIDUAL DECISION STYLE

NR DSA-010
Decision Science Consortium, Inc./Cohen & Chinnis

Scientific Objectives: Decision-making style for a wide range of users is defined and measured within the context of a decision-support system. User accommodation to analytic decision-aids that provide guidance against bias or error is assessed. Principles are defined and expressed within independent software modules that provide flexible interfaces with the user that are consistent with individual decision-making styles and facilitate those strategies.

Approach: Decision aids are developed that accept the user's personal preferences but through channeling and prompting suggest optimal decision strategies consistent with those preferences. Individual differences in method of problem structuring and analysis, organization, and searching a data base, are accommodated for styles that range from the intuitive to the analytical. Coupled with this capability, the decision aid monitors the user's decision strategy and suggests potential biases or errors that are evident in the user's decision-making. The decision-support system consists of a data base for the task, an analytic model of the task, a planning module for interacting with the data base, and other software modules that allow the user to select the relevant parts of the data base, to insert judgments, to evaluate the options presented, to monitor conclusions from the analytic model, and to alert the user when a decision differs significantly from norms.

Progress: A prototype aid was developed and tested successfully for tactical decisions made by submarine commanders relative to the launching of an attack against a target. The aid has currently been extended to the more general situation of a manager's selection of a new employee among a number of applicants. This latter decision aid has been designed in six modules: (1) knowledge base - decision task and its context; (2) adjust - user changes the knowledge base; (3) decide - user specifies strategies and options; (4) select - user manipulates subsets of the knowledge base; (5) alert - system prompts user about significant options; and (6) advisory - system prompts user about suboptimal strategies. The implementation of the decision aid has been partially achieved on an IBM-AT system in the C language.

Potential Applications: The personalized/prescriptive design principles for an interface to a decision-support system have been demonstrated to be effective in tactical situations and a multi-attribute choice situation. The generality of this system suggests that such decision aids would be suitable for planning, policy options, and management decision-making.

* * * * * *

THE FOLLOWING WORK UNIT WAS COMPLETED DURING THE PAST YEAR:

FLEXIBLE GRAPHICS WORKSTATION FOR DECISION MAKING
NR DSA-009
Visual Intelligence Corporation/Morse

Scientific Objectives: Define and validate cognitive-interface principles during interactive experiments on a workstation providing graphic presentations of complex, time-varying and dynamic data.

Approach: A prototype workstation was designed, assembled and tested with experienced users who performed real-time analysis and extraction of information from large data bases. A representative task environment was simulated that encompassed problems that surround real-time decision making. A series of experiments validated design principles for the user interface of that prototype workstation under these conditions: (a) simultaneous and/or sequential display of data in multiple formats; (b) embedding of static data-displays in user-created backgrounds; (c) dynamic formatting of data displays; (d) introduction of event monitors as an aid to user strategy in reacting to real-time data; and (e) the effect of total-system context on user performance. A series of experiments validated the display principles for the user interface by formal evaluation with novice users as test participants.

Results and Conclusions: Software modules were designed and written for the graphics display system; they included modules for: (a) a user interface to system functions; (b) an interactive facility for the construction of display formats; (c) a computer-aided design aid for the construction of background contexts; (d) an intelligent event monitor; and (e) a data system interface. Formal testing of the system with novice users demonstrated that the design principles incorporated into the workstation facilitated the encoding, retrieval, and modification of data, as well as the monitoring of significant changes in large data bases.

Potential Applications : In Navy information handling systems where there is an operational requirement at various user levels to reach quick decisions based on the review of large amounts of information, interactive workstations will be effective. Graphic displays, in flexible formats chosen by the user, stored in knowledge bases, and triggered by various event conditions, show great promise to achieve needed capability.

GROUP PSYCHOLOGY RESEARCH PROGRAMS

(CLUSTER F-I)

From 1973 to 1984 this program was called "Organizational Effectiveness" and aimed at understanding the variables that determine the job performance, morale, retention, and quality of working life of members of work organizations. During that period we funded a number of field studies dealing with organizational theory and organizational behavior. At the end of 1984, we changed our name to "Group Psychology," and decided to phase out our organizational research. We intended to focus on formal models and theory-guided, controlled experimentation on performance in small groups -- especially those which work under stressful conditions or are hierarchically organized. During this year, ONR management has reassessed the total range of life sciences which it desires to support, and has concluded that Group Psychology cannot be assigned a high priority. In FY 1987 this domain will not appear as an ONR program.

Our research during the period covered by this volume consisted of three clusters described below: F. "Effective Heterogeneous Groups," G. "Turnover and Retention," and H. "Productivity."

Cluster I contains contracts belonging to an Exploratory Development (6.2) program on Manpower R&D, managed by Dr. Stan Collyer in ONR's Technology Programs Directorate. It is multidisciplinary, with specific contracts monitored by Scientific Officers in both the Psychology Sciences and Mathematical Sciences Divisions. Within the Psychological Sciences Division, the Manager of the Group Psychology Research Programs serves as Manager.

F. EFFECTIVE HETEROGENEOUS GROUPS

ONR-sponsored research on intergroup relations and the functioning of heterogeneous groups began in the early 1970s when the Armed Services dropped conscription and increased their recruitment of minorities and women (and when a number of well-published racial incidents occurred in the Navy and Marine Corps). ONR's initial efforts, designed to increase the knowledge base needed to improve intergroup relations, included laboratory and field studies on the dynamics of interactions among persons from different cultural, ethnic, and racial groups.

In the late 1970s and the 1980s, our research in this area has concentrated on identifying the situations and contexts that contribute to the effective functioning of heterogeneous groups in high-technology organizations. A number of efforts aimed at deepening our understanding of the factors affecting intergroup and interpersonal behavior. They included research on cognitive organization of information about persons from different groups, determinants of attitudes toward different ethnic and racial groups and the effects of organizational membership on intergroup behavior. Several contracts explicitly focused on the economic, social, psychological, cultural, and vocational variables critical to successful recruitment, education, training, management, and retention of minorities in high-technology occupations. This research, when completed over the next year or two, will provide information about organizational contexts, which when combined with what we learned previously about the perceptions and motives of minorities and the behavioral responses of minority and majority persons to each other, will provide a substantially improved technology base.

At this point, therefore, it is appropriate to terminate our financial support of research in this area and provide an opportunity for the Navy's applied R&D and operational manpower programs to transition the products of our past basic research. As a matter of fact, the Navy has already made substantial progress in applying the results of such past psychological research in the form of the Navy Organizational Effectiveness Program (formerly the Navy Human Resources Management Program) managed by the Deputy Chief of Naval Operations (Manpower, Personnel, and Training). In addition, the current success of the Navy in recruiting and retaining minorities in the enlisted ranks suggests that a number of management lessons have already been learned that might well be applied now to recruitment of minority officers, where there is still room for improvement. All in all, this seems an opportune time to turn our basic research attention to other areas where the technology base still needs strengthening and/or where exciting discoveries are being made.

THE USE OF COOPERATIVE LEARNING PROCEDURES WITH HETEROGENEOUS TEAMS IN HIGH-TECHNOLOGY ORGANIZATIONS

NR 170-967
University of Minnesota/Johnson & Johnson

Scientific Objectives: To develop and refine a theoretical model concerning the internal dynamics and processes of cooperative learning groups. To conduct experimental research on the use of cooperative learning groups with the learning of technical material at the computer.

Approach: The basic field-experimental design for this research program involves young adults from secondary schools and from ROTC programs on two campuses. Students are randomly assigned to an individualistic condition, where each student works alone toward a set criteria, a competitive condition where each student works to do better than classmates, or one or more cooperative conditions where students work together in small squads to make sure all of them have learned the material. A range of different cooperative conditions are being investigated with three studies being conducted each year. Some of the internal dynamics of student/student interaction being examined include: different goal structures (cooperative, competitive, and individualistic), levels of cognitive reasoning, mode of participation, and purpose of the learning.

Progress: Study one used a computer program on navigational skills with secondary school students. Students in the cooperative/computer condition scored higher on the achievement and attitude measures than did students in a competitive/computer condition or an individualistic/computer condition. There seem to be some advantages to structuring learning teams at a computer even if there are enough computers to send students to a computer alone. Study two examined the effects of controversy in a cooperative condition. The university-level engineering students in the controversy condition produced significantly better final reports and more positive attitudes toward controversy than classmates in the no-controversy condition while the students in the no-controversy condition were more positive about the subject matter.

Potential Applications: This research will provide specific strategies for structuring cooperative learning groups to maximize the learning of technical material in Navy and other high-technology training programs.

Reports:

Johnson, R. T., Johnson, D. W., & Stanne, M. B. The Effects of Cooperative, Competitive, and Individualistic Goal Structures on Computer-Assisted Instruction (TR-ONR-2). University of Minnesota, Dept. of Ed. Psych.

Smith, K. A., Petersen, R. P., Johnson, D. W., Johnson, R. T. The Effects of Controversy and Concurrence Seeking on Effective Decision Making (TR-ONR-3). University of Minnesota, Dept. of Ed. Psych.

Yager, S., Johnson, R. T., Johnson, D. W. The Impact of Group Processing on Achievement in Cooperative Learning Groups (TR-ONR-4). University of Minnesota, Dept. of Ed. Psych.

Yager, S., Johnson, R. T., Johnson, D. W. Oral Discussion , Group-Individual Transfer and Achievement in Cooperative Learning Groups (TR-ONR-5). University of Minnesota, Dept. of Ed. Psych.

Johnson, R. T., Johnson, D. W., Stanne, M. B. A Comparison of Computer-Assisted Coperative, Competitive, and Individualistic Learning (TR-ONR-6). University of Minnesota, Dept. of Ed. Psych.

Johnson, D. W., Johnson, R. T. Computer-Assisted Cooperative Learning (TR-ONR-7). University of Minnesota, Dept. of Ed. Psych.

Lew, M., Mesch, D., Johnson, D. W., Johnson, R. T. Effects of Collaborative-Learning: Contingencies on the Social Interaction of Isolated Students (TR-ONR-8). University of Minnesota, Dept. of Ed. Psych.

Lew, M., Mesch, D., Johnson, D. W., Johnson, R. T. Positive Interdependence, Academic and Collaborative-Skills Group Contingencies and Isolated Students (TR-ONR-9). University of Minnesota, Dept. of Ed. Psych.

CAREER ATTAINMENT FOR WOMEN, BLACKS AND HISPANICS IN CIVILIAN AND MILITARY HIGH-TECHNOLOGY ORGANIZATIONS

NR 170-968
Johns Hopkins University/Braddock & Crain

Scientific Objectives: This research is testing social status attainment hypotheses which seek to explain the process of identifying, recruiting, and training blacks, hispanics and women across a wide range of high-technology occupations. Private firms, public agencies, and military commands of different sizes and in different locations are being investigated.

Approach: The National Longitudinal study of the High School Class of 1972 developed by the National Center for Education Statistics has been enhanced by information from public and private employers on practices related to the jobs held by these young adults, and by data from Department of Defense sources on the military careers of these individuals. This work differs from most previous research by combining individual variables, such as educational background, with labor market variables, such as employer practices, and by studying various stages of the employment process (recruitment, selection, training, turnover or promotion).

Progress: The early stages of this project were devoted to building a data base which includes information on firms and local labor markets as well as individuals. Census data on local labor markets and new data from a nationwide survey of 4078 employers with data from a seven year follow-up of the National Longitudinal Study have been merged. A critical review of the literature and some preliminary findings relating recruitment practices to race and gender representation in the work force were presented at ONR conferences in 1983, and subsequently released as a Technical Report in 1984. Presentations based on current findings were presented at the American Sociological Association and the American Educational Research Association during 1985 and will be released in a technical report during 1986.

Potential Applications: Any organization, whether a school, a firm, or a military command, that wants to increase the representation of minorities or women in high-technology fields must consider at what point(s) it can intervene most effectively in the employment process and how. This research will provide a theoretical basis for such decisions.

Reports:

Braddock, J. Recruitment and selection of minorities in high-tech organizations: A sociological perspective (TR-ONR-1), The Johns Hopkins University, Center for the Social Organization of Schools, 1985 (ADA 151-547).

INFERENCE PROCESSES IN ATTRIBUTION AND ATTITUDE FORMATION
NR 170-969
Purdue University/Smith

Scientific Objectives: Test and extend a new theory of social inference processes, including those involved in person perception, causal attribution, and attitude formation. The theory is based on a general theory of memory and cognitive processes; thus, the overall research objective is to create closer theoretical linkages between social cognition and cognitive psychology.

Approach: Laboratory experiments and analysis of non-experimental (survey) data focus on the following issues related to the theory: the automatization of social inference processes, people's ability to verbally report on their use of inference procedures, the effects of salience on the types of inferences made, and the implications of inference processes for the long-term memory structure of an attitude.

Progress: Studies have been conducted on the following basic issues. (1) The development of automatic procedures for social judgments, including increases in speed and efficiency of judgments with practice. Consistent with the theory, results show that as they become automatized social judgment processes display changes that parallel those that have been found with nonsocial judgments. (2) The role of procedural knowledge in category accessibility effects: procedural knowledge, an important component of the theory, has been shown to be implicated in long-lasting effects of exposure to information related to a social category (such as hostility) on later interpretations of people's behaviors. (3) The structure of knowledge about persons--incuding stereotypes--in memory: Knowledge about other persons is organized in memory around concepts of traits, roles, and goals, and can be accessed efficiently to make inferences about other people.

Potential Applications: The theory of social inference, and the research supporting it, have potential applications to stereotyping, person perception, and intergroup attitudes. The processes underlying stereotyped inferences about people's personality characteristics or ability based on their race, gender, or ethnicity will be clarified by the research, and possible means of avoiding stereotype-based biases in judgment may be pointed out.

Reports:

Smith, E. (1985). The development of automatism of social judgments (TR-ONR-4). Purdue University, Psychology Department.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

AN EXAMINATION OF HISPANICS AND GENERAL POPULATION PERCEPTIONS OF ORGANIZATIONAL ENVIRONMENTS

NR 170-906
University of Illinois/Triandis

Scientific Objectives: To compare the subjective cultures of Hispanics and samples of the general population, using both anthropological and psychological approaches as well as a hybrid approach developed by Triandis. To suggest how subjective culture information can be used to improve recruitment, training, and retention of Hispanics in high technology organizations.

Approach: Intensive interviews and observations in Navy recruitment and training settings resulted in hypotheses about significant differences in the subjective cultures of Hispanics and Non-Hispanics. Instruments developed to test these hypotheses included both emic (unique to Hispanics) and etic (common to the two populations) elements. Findings obtained with Navy personnel were cross-validated with Hispanic and Non-Hispanic high school students and against data from the National Longitudinal Survey. The methodologies included idiographic analyses, the determination of the acculturation level of each individual, the use of multidimensional scaling, and factor analyses of the responses obtained from each sample.

Results and Conclusions: Theoretical results centered around a better understanding of the constructs of collectivism (which is an important element of Hispanic culture) and individualism (which is an important element of Non-Hispanic culture). In addition, one study made a contribution to the debate of "What is culture?", and how it should be conceptualized for optimum progress in the social sciences. Methodological results centered around the issue of whether or not one obtains substantial advantages by developing locally sensitive (emic) instruments for the study of cultural differences. It was found that while emic instruments are expensive to develop they do identify more cultural differences than etic instruments. On the other hand, very large cultural differences can be identified with even the crudest pseudo-etic instruments. Numerous papers were published that discussed the question of equivalence of measurement in cross cultural research.

One of the studies examined the behavior of bilinguals responding to counterbalanced forms of the same questionnaire and tested the hypothesis that social desirability influences the responses of the bilingual in the language of the culture with which the bilingual does not identify very strongly. Another methodological issue is how to handle acculturation in cross-cultural studies. It was shown that acculturation influences the obtained results differently for different topics: Elements of subjective culture closely linked to behavior converge to the responses of the group that a minority is acculturating to, but elements that are not closely linked to behavior do not show such convergence.

Potential Applications: An understanding of the characteristics of people from the collectivist Hispanic culture could improve their recruitment, training and retention in individualistic high-technology cultures such as the Navy.

Reports:

Triandis, H.C. (1985). An examination of Hispanic and general population perceptions of organization environments: Final Report. University of Illinois, Psychology Dept., August 1985. (A158672)

Archival Publications:

Triandis, H. C. et al. (1984). Simpatia as a cultural script of Hispanics. Journal of Personality and Social Psychology, 47, 1363-1375.

Triandis, H. C. (1984). A theoretical framework for the more efficient construction of culture assimilators. International Journal of Intergroup Relations, 8, 301-330.

Hui, C. H., & Triandis, H. C. (1985). Measurement in cross-cultural psychology: A review and comparison of strategies. Journal of Cross-Cultural Psychology, 16, 131-152.

CHANGING RACE RELATIONS IN MANAGEMENT
NR 170-943
Yale University/Alderfer

Scientific Objectives: To assess the consequences of long-term intergroup intervention for achieving attitudinal and structural change in the relations between black and white managers; to examine and explain the underlying dynamics associated with change and resistance to change in race relations in large organizations.

Approach: In contrast to the existing paradigm from social psychology based on the "contact hypothesis," the present framework utilized concepts from embedded intergroup relations theory. The intervention methodology after diagnosis consists of three major components: (1) a twenty-person race-relations advisory group balanced by race, gender, rank, and department; (2) an upward-mobility program designed to select managers for potential advancement, independently of, and in coordination with, normal promotion procedures; and (3) a race-relations competence workshop created to teach black and white managers the concepts and behaviors necessary to improve the overall race relations of the organization. Assessment of the effects of the interventions was done by means of a variety of measures including the products of the advisory committee, the qualities and race-gender mix of the people selected for advancement potential, the change in proportions of black managers in higher level positions throughout the corporation, the participation of black managers in decision-making about the careers of lower ranking employees, and the concepts and attitudes of individuals who participate in the race relations workshops. This project occurred in an organization with more than 12,000 employees, 3000 managers, and 200 black managers.

Results and Conclusions: An historical study of the Race Relations Advisory Group identified phases in the life of the group and related the development periods to group products, internal relationships among members, and external transactions between the advisory group and key units from the organizations. Intervention procedures for the corporation's upward mobility system were derived from the theory. Results of the intervention were examined at each phase of the program and demonstrated the effects of both progressive and conservative forces in response to the change program. The Race Relations Competence Workshop was designed in accord with the theory, provided opportunities for managers to learn how to manage racial dynamics more effectively, and provided further insights into the collusive patterns of interpersonal relationships within and between the racial groups. Systematic evaluation data suggest that blacks evaluated the workshop more favorably than whites, and whites increased their awareness of racist behavior patterns more than blacks.

Potential Applications: The method and theory used in this study have potential applicability in any large predominantly white organization that has a significant number of black members, a professional human resource program, and a commitment from senior officials to support progressive race relations. Advisory group composition, mobility management, and workshop design all lend themselves to being adapted to the special conditions of the Navy, if the other conditions can be met by specific organizational units.

Reports:

Alderfer, Clayton P. (1985). Introduction to Changing Race Relations in Management (Technical Report 3). New Haven: Yale University, School of Organization & Management.

Alderfer, Clayton P. (1985). Changing Race Relations in Organizatons: A Comparison (Technical Report 4). New Haven: Yale University, School of Organization & Management.

Alderfer, Clayton P. (1985). The Race Relations Advisory Group: An Intergroup Intervention (Technical Report 5), New Haven: Yale University, School of Organization & Management.

Alderfer, Clayton P. and Tucker, Robert C. (1985). Measuring Managerial Potential and Intervening to Improve the Racial Equity of Upward Mobility Decisions.(Technical Report 6). New Haven: Yale University, School of Organization & Management.

Alderfer, Clayton P., Alderfer, Charleen J., Tucker, Robert C., and Tucker, Leota M. (1985). The Race Relations Competence Workshop: An Intergroup Educational Procedure (Technical Report 7). New Haven: Yale University, School of of Organization & Management.

Alderfer, Clayton P. (1985). Time Series Evaluation of Race Relations Improvement (Technical Report 8). New Haven: Yale University, School of Organization & Management.

Alderfer, Clayton P. (1986). Comparison of Perceptions About Race Relations Before and After Long Term Intergroup Intervention (Technical Report 9). New Haven: Yale University, School of Organization & Management.

Archival Publications:

Alderfer, C. P. (1986). An integrated perspective on group dynamics. In Jay Forsch (Ed.), Handbook of Organizational Behavior. Englewood Cliffs, N.J.: Prentice Hall.

G. PERSONNEL TURNOVER AND RETENTION

Investigators in this cluster have been examining the important variables related to: individual characteristics and attitudes (such as organizational commitment) which predict personnel turnover; the manner in which features of the organization (e.g., leadership and management) are related to turnover; the impact of turnover on productivity and organizational effectiveness; and the discovery of new methods to reduce turnover.

A simple measure of the number of individuals retained by an organization cannot be used as the sole index of the effectiveness of the organization. Instead, one must look at the extent to which high performing individuals are not only retained but allowed to develop in a setting which fosters positive work attitudes. These attitudes, in turn, can be a critical link in reducing personnel turnover and increasing productivity. Our research in this area has been characterized by the creation and testing of longitudinal and multivariate models, and has been concerned with the influence on turnover of personnel policies and incentive plans, changes in job scope, and the role of the supervisor. In a broader career development approach, we have funded investigations of the role of family factors in Navy reenlistment, and the interaction between organizational socialization practices and individual career decision making.

Two factors demand terminating our support of research in this area. First, we have recently completed a number of major efforts directed at personnel turnover which have produced theories, models and instruments which considerably improve our ability to predict the extent of turnover, influence its incidence, and accommodate to its effects. Two recent books (Employee-Organizational Linkages by Mowday, Porter, and Steers and Employee Turnover - Causes, Consequences, and Control by Mobley) summarize much of the recent ONR turnover research and document rather substantial advances in this field of research. Second, the Chief of Naval Operations announced in September 1984 that retention of Navy personnel has reached an all-time high of 60% of those in their first enlistment, 67% of those in the second enlistment, and 95% of those beyond the second enlistment. Also, recruiting has improved to such an extent that 93% of the new enlistees have high school diplomas. This represents a major change since the advent of the all-volunteer Navy (which is when we began increasing our research on recruiting and retention). Since improved recruitment and retention programs do not have the urgent priority they warranted in the 1970s, it is appropriate for us to turn our research attention to other, more critical areas.

THE IMPACT OF FAMILY STRUCTURE ON THE STRUCTURE OF WORK

NR 170-956
Northwestern University/Yogev & Brett

Scientific Objectives: Specific objectives include the identification of the job behaviors and family-oriented behaviors that conflict, the identification of occupational cultures in which work behaviors are changing and the development of psychometrically sound techniques for measuring changes in work behaviors.

Approach: The investigators developed new instruments, models and analytic techniques. New instruments include a family-involvement scale and measures of the degree of deviation from work norms about hours of work, place of work, social, travel, relocation, and physical energy-health. These deviation measures are the dependent variables. Independent variables are: organization culture, labor economic conditions, job involvement, family involvement and career stage. The model to be tested is at the couples level of analysis; that is, interest is in the causal relationships between spouses' work-role restructuring. Structural equation modeling is used to test the model.

Progress: In the main study, we are studying couples who fit into the following patterns developed in the pilot research: both high work-involved; he high work-involved, she low; and vice versa. Working with several Chicago area organizations, a target group of employees was located and interviewed about the norms of widely held beliefs about what behaviors are necessary to get ahead and/or be seen as an effective performer in that company. The interview was followed by a questionnaire to couples in each organization. Questionnaire data are used to test the model.

Potential Applications: The major use of the results of this research is in strategic human resource planning. As the workforce absorbs more and more working women with children, organizations are going to have to change corporate norms in order to keep these women and/or their husbands who also have family responsibilities. Our studies will identify conditions under which norms are violated and provide a cross-fertilization of ideas about building-in flexible structures.

Archival Publications

Yogev, S. (1985). Perceptions of the division of housework and childcare and marital satisfaction, Journal of Marriage and the Family, 47, 3, 609-618. (AD A131761).

REACTIONS TO JOB CHANGES
NR 170-959
University of Wisconsin/Dunham

Scientific Objectives: To assess worker focus of attention (on/off the job), absorption with or distraction from the job, and support for/resistance to organizational change. To assess the impact of existing job differences versus job changes. To develop a system for anticipating and managing the climate for organizational change. To explore the processes involved in the development of organizational commitment from the time of organizational entry.

Approach: Data are being collected through a series of field surveys, organizational simulation experiments, and field experiments. Subjects include paid subjects and volunteer organizational members (from low-level hourly employees through upper-level management). Statistical techniques include multiple regression, analysis of variance, multivariate analysis of variance, and factor analysis. Innovative approaches include a new content analysis procedure, and development of new measures of important constructs previously not measured effectively (such as absorption/distraction, orientation toward change, etc.)

Progress: Primary research emphasis in this year has been on the development and examination of a new construct called "focus of attention." At a basic level focus of attention is defined as what a person thinks about while at work, including both the direction and intensity of the thoughts. Through data collection at six different organizations, focus of attention has been measured, the construct validated, and several hypotheses tested. Its importance for understanding worker reactions is clear. It has been shown to influence reactions to variations in job design, leader behavior, and work-unit structure. A second line of effort has identified several attitudes underlying attitude toward change, an instrument has been developed, data collected, and initial validation tests have been conducted. A third effort has examined worker reactions to job redesign, and the importance of attitude toward change has been documented in a series of job redesign interventions.

Potential Applications: Diagnosis of probable support for/resistance to specific organizational changes. Assessment of degree to which organizational members are focusing on job versus non-job factors and the impact of this on organizational policies. Better understanding of the process by which commitment to the organization is developed.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

THE EFFECTS OF ORGANIZATIONAL SOCIALIZATION ON CAREER OUTCOMES
NR 170-911
M.I.T. Sloan School of Management/Schein, Bailyn, Van Maanen

Scientific Objectives: To explore the interaction between the individual and the organization, investigating the effects of culture, socialization processes, and human resource policies to determine their effects on organizational functioning and individual satisfaction.

Approach: This project was a multi-method project focusing primarily on ethnographic, clinical, and exploratory survey methods. The variables needing investigation are not well understood and no ready-made instruments exist to study them. Approaches were chosen to lead to understanding in greater depth the meaning of such concepts as culture, socialization, organization, individual career, etc. The investigators also decided to study a few organizations and occupations in depth rather than doing extensive statistical analyses.

Results and Conclusions: At the outset we found that much more effort had to be devoted to defining and delineating key concepts such as culture. In fact, as the final report shows, we still have a way to go before we can unambiguously define what culture is, much less how it evolves, changes, and affects other things such as careers. Human resource policies are typically built on oversimplistic assumptions abut career motivations, leading to some counterproductive and paradoxical outcomes, especially in technically based careers and organizations. Finally, we found that organizations are more complex than we had initially thought, requiring more qualitative, clinical and ethnographic research methods. In using these methods we also found that research in these areas was itself in need of definition and refinement, and devoted a technical report to research methods.

Potential Applications: The findings will have implications for personnel and managerial policy with regard to the management of technical and managerial personnel.

Reports :

Dougherty, Deborah (1985). Culture, Socialization, and Careers : The Individual and the Organization (Final Report, Vol. 1: Theories, Concepts, and Ideas; Vol. II: Contexts, Findings, and Ideas; Vol. III: Ideas on Methods; Vol. IV: Tools and Ideas for Practice). MIT, Sloan School.

Archival Publications:

Arthur, M. B., D. J. Levinson, E. Schein, and M. A. Shepard (1984). Working With Careers. Center for Research in Career Development, Columbia University School of Business, 1984.

Bailyn, Lotte (1985). Autonomy in the industrial R&D lab, Human Resource Management, 24, 129-146.

Bailyn, Lotte. Issues of work and family in Organizations: Responding to social diversity. In Working with Careers, Arthur, et al., op.cit.

A DEVELOPMENTAL THEORY OF WORK MOTIVATION
NR 170-926
Pennsylvania State University/Landy

Scientific Objectives: Current motivational theories (e.g., reinforcement, need, social comparison, and cognitive) were examined with the intention of developing an integrated theory of motivation. The proposed theory was based on two assumptions: that individuals vary with respect to the mechanisms by which they are motivated; and that these mechanisms change over time.

Approach: Comparisons were made of various incentives for individuals at different career stages. A sample of individuals was followed over a three-year period to assess changes in the values they apply to different types of incentives. Questionnaires included biographical data, occupational/student/military status, vocational preference, motivational measures, and self-ratings of self-esteem.

Results and Conclusions: Traditional approaches to understanding work motivation have not been successful and so middle-range theories are necessary for progress in this area. Cognitive processes will play a major role in motivation theories of the future and various middle-range theories are likely to be more suitable for understanding some dependent variables than others. To facilitate such future research, a taxonomy of motivation theories was developed and examples of each category were analyzed.

Potential Applications: This research will help direct researchers to the new conceptions necessary in order to make motivational theories useful in predicting individual work performance.

Reports:

Landy, Frank J. and Becker, Wendy S., (1985). Final Report: Adaptive Motivation Theory (ONR-85-1). Pennsylvania State University, Paychology Department.

A TRIPARTITE APPROACH TO EVALUATING PERSONNEL/HUMAN RESOURCE DEPARTMENT EFFECTIVENESS

NR 170-963
Duke University/Tsui

Scientific Objectives: The effectiveness of the personnel subunit can be evaluated by the activities it performs, the criteria it optimizes, and the multiple constituencies it satisfies. This research tested several hypotheses specifying the relationships among the personnel department's activities, criteria, reputation and the effectiveness of the larger organization in which the subunit is located.

Approach: A combination of interviewing, Delphi, and mailed surveys was used to collect data. Delphi was used to define the domain of personnel activities and evaluation criteria. Interviewing and surveys were used to obtain preferences for, and evaluation of, personnel department tasks by the multiple constituencies. The sample for the first study was 150 field personnel units in three multi-divisional corporations or institutions. The sample for a second study was 300 small-sized to medium-sized firms. Data included both subjective opinions and institutional records. Multivariate statistics were used to analyze the data.

Results and Conclusions: The research reveals that the personnel subunit performs nine general human resource functions. The nine functions include both routine, administrative tasks and proactive, strategic activities. Clients placed high importance on both administrative services and employee relations activities. Actual personnel unit actions also emphasized consistency in policy applications. Effective personnel units were able to obtain support from their clients who have resources such as time, ideas, and money, and provided solutions to critical organizational problems such as productivity and employee relations. Further, effective personnel units gave timely responses to client needs. Finally, the contribution of personnel unit activities to organizational effectiveness was observed by the significant correlations between this unit's innovativeness, efficiency and resource acquisition and organizational effectiveness criteria such as job satisfaction, organizational commitment, intention to stay with company, absenteeism, and perceived operational effectiveness.

Potential Applications: Findings should lead to improved organization of personnel departments; definition of activities and evaluation criteria; allocation of resources and effort across multiple activities, criteria and constituencies; and an evaluation process that addresses the interests and requirements of the beneficiaries of personnel department efforts.

Reports:

Tsui, A. S. and Milkovich, G. T. (1985). Dimensions of personnel department activities; an empirical study. (Res. Rep. ONR-85-1). Duke University, Fuqua School of Business

WORK AND THE PERCEIVED QUALITY OF LIFE
NR 170-964
State University of New York, Buffalo/Rice

Scientific Objectives: The perceived quality of life (pQL) concerns how people feel about their lives, as a whole (overall pQL) or with regard to specific domains of life e.g., the perceived quality of work life). This research tested hypotheses concerning determinants of pQL and the manner by which work experiences affect overall pQL.

Approach: Correlational analyses of questionnaire data were used to test these hypotheses. Such analyses were performed with large (N=1000) national survey data sets obtained through ICPSR and with small (N's= 48-141) original data sets obtained from local surveys of employees, students, and the unemployed. Self reports of satisfaction, happiness, and related evaluations of life were the principal criteria in these analyses. Predictor variables included: a) job characteristics; b) importance of work and nonwork roles; c) conflict between work and nonwork roles; and d) three variables concerning outcomes associated with participation in different life domains (amount of each outcome received, amount wanted, and importance of the outcome).

Results and Conclusions:

Results generally supported hypotheses derived from the conceptual model of pQL. Specifically, (1) The sum of domain pQL scores (e.g., satisfaction with job or family) was predictive of overall pQL; (2) Work-family and work-leisure conflict were the only work-related variables with relationships to overall pQL that were mediated through causal pathways involving both the quality of work life and the qualify of nonwork life; (3) Conflict between work and family was highest for people ascribing high importance to both domains; (4) pQL was better predicted from the discrepancy between what people get (outcomes) and what they want (standards) than from just what they get; (5) The utility of importance (values) in predicting pQL depended on the type of predictor scores with which importance information was used--when used with outcomes, importance scores enhanced prediction of pQL, but when used with satisfaction score predictors, importance did not enhance prediction of pQL.

Potential Applications: Prior research has shown that pQL is related to outcomes of both economic and humanistic concern to organizational decision makers, e.g., turnover, absenteeism, and physical health. Programs seeking to control such outcomes would benefit from a conceptual model clarifying the basic processes determining pQL, and the links between work experiences and pQL.

Reports:

Rice, R. W., Bonacci,M. & Bunker, B. (1985). *Involvement with Prior Job, Social Support, and the Perceived Quality of Life Among the Unemployed* (Tech. Rep. NO ONR-3). (AD-A162102).

Rice, R., Frone, M. & McFarlin, B. (1985). *Inter-domain Fit and the Perceived quality of life* (Tech. Rep. ONR-4). (AD A161993).

Rice, R., McFarlin, B., Hunt, R. & Near, J. (1985). *Job importance as a moderator of the relationship between job satisfaction and life satisfaction* (Tech Rep. ONR-5). (AD-A162105).

Archival Publications:

Rice, R. W., McFarlin, D. B., Hunt, R. G., & Near, J. P. (1985). Organizational work and the perceived quality of life: Toward a conceptual model. *Academy of Management Review*, 1985, *10*, 296-310. (AD A161993).

H. PRODUCTIVITY IN ORGANIZATIONS

In light of the changed focus of this Program in fiscal year 1985, we will not support new research on productivity.

THE DESIGN AND MANAGEMENT OF WORK TEAMS
NR 170-912
Yale University/Hackman

Scientific Objectives: To advance theory about small group performance; to generate findings that are of practical use in the design and management of teams in organizations, and to develop research methodologies that are particularly well-suited for the study of group effectiveness.

Approach: Intensive study of a variety of work teams in organizations, using multiple methodologies (including self-report, observational, interview, and archival methods). The main sample is about 30 highly diverse teams which have been studied in depth. In addition, a large number of teams, studied less intensively, are being used for psychometric analyses aimed at refining the data-collection instruments. Finally, a subset of teams in the main sample are being used in action-research projects aimed at assessing the usefulness of the concepts and methods in bringing about improvements in actual team performance.

Progress: Data collection is complete and data analysis is nearing completion. Findings to date suggest that the design of work groups (i.e., their composition, their tasks, and the core norms that guide member behavior) and the properties of the organizational context in which they operate are especially potent in affecting team performance. These findings provide a way of understanding group effectiveness that contrasts with previous research focused on the patterns of interpersonal behavior that occur among group members. Work is underway on a number of major publications.

Potential Applications: The normative model of team effectiveness being tested and refined in the research program can be used to guide the design and management of groups that perform tasks in organizational settings. Specific strategies for using the conceptual model and research findings for this purpose are presently being developed and assessed.

Archival Publications:

Hackman, J. R. (1985). Doing research that makes a difference. In E. E. Lawler, A. M. Mohrman, S. A. Mohrman, G. E. Ledford & T. G. Cummings (Eds.), Doing research that is useful for theory and practice. San Francisco: Jossey-Bass.

Hackman, J. R. (1985). The commitment model: From "whether" to "how." In K. B. Clark, R. H. Hayes & C. Lorenz (eds.), The uneasy alliance: Managing the productivity-technology dilemma. Boston: Harvard Business School Press.

Hackman, J. R. (1986). The design of work teams. In J. Lorsch (Ed.), Handbook of organizational behavior. Englewood Cliffs, NJ: Prentice-Hall.

INFORMATION PROCESSING
NR 170-950
Texas A&M University/Daft & Griffin

Scientific Objectives: This effort aims to develop new and more sophisticated theoretical frameworks for understanding different methods of information-seeking and information dissemination by managers as a function of variables such as the complexity of the tasks they deal with, the manager's level in the hierarchy, and changes in the organization's environment.

Approach: Theory and model building are undertaken to explicate how information processing is likely to occur in organizations. Laboratory studies are conducted to test how various kinds of information-processing manipulations influence perceptions of the work place. Field research using survey instruments, archival documents, and interviews provides data to refine the models and extend the laboratory findings.

Progress: Work is proceeding on three tracks. First, a model has been proposed and tested, dealing with the relationship between media richness and managerial information processing. Findings indicate that managers tend to prefer rich, oral, face-to-face media, when learning requirements are high, but written media when learning requirements are low and routine. Second, a model has been developed and partially tested, with results suggesting that, with regard to an employee's perception of the work environment, information received from other people is as important as are the objective facts of the situation. Third, a model is under development dealing with organizations viewed as systems for interpreting information; testing will follow development.

Potential Applications: Results will help to define the most effective managerial behavior in a variety of situations. The work on matching the choice of information medium to the nature of the information to be communicated will enhance the design of management information systems for maximal utilization, while work on managers' choice of cues and media for transmitting information will contribute to the training of managers for maximal effectiveness.

Reports:

Griffin, R., Bateman, T., Wayne, S., and Head, T. (1984). Objective and Social Factors as Determinants of Task Perceptions and Responses: An Integrative Framework and Empirical Investigation (TR-ONR-DG-09). Texas A&M University, Department of Management.

Daft, R. and Lengel, R. (1984). A Proposed Integration Among Organizational Information Requirements, Media Richness and Structural Design (TR-ONR-DG-10). Texas A&M University, Department of Management.

Giroux, G.A., Mayper, A. G., and Daft, R. L. (1984). Toward a Strategic Contingencies Model of Budget Related Influence in Municipal Government Organizations (TR-ONR-DG-11). Texas A&M University, Department of Management.

MacIntosh, N. B. and Daft, R. L. (1985). *Technology, Personal Attributes and the Perceived Amount and Focus of Accounting and Information System Data* (TR-ONR-DG-12). Texas A&M University, Department of Management.

MacIntosh, N. B. and Daft, R. L. (1985). *Management Control Systems and Interdependencies: An Empirical Study* (TR-ONR-DG-13). Texas A&M University, Department of Management.

Head, T. C., Yates, V. L. Griffin, R. W. and Bateman, T. S. (1985). *The Priming Effect in Task Design Research* (TR-ONR-DG-14). Texas A&M University, Department of Management.

Griffin, R. W., Skivington, K. D., and Moorhead, G. (1985). *Symbolic and Interactional Perspectives on Leadership: An Integrative Framework* (TR-ONR-DG-15). Texas A&M University, Department of Management.

Griffin, R. W., Bateman, T. S. (1985). *Job Satisfaction and Organizational Commitment* (TR-ONR-DG-16). Texas A&M University, Department of Management.

PERFORMANCE APPRAISAL -- MEMORY AND RECALL PROCESSES AS THEY AFFECT APPRAISER ACCURACY

NR 170-960
University of Connecticut/Barnes-Farrell

Scientific Objectives: The research is designed to explore performance appraisal from a process perspective. Specifically, it focuses on gaining a better understanding of the ways in which memory and recall processes affect appraiser accuracy.

Approach: Two phases are involved: (1) the development of stimulus materials and measures of accuracy in performance appraisal; (2) the use of these materials in laboratory studies to test hypotheses generated from social cognition models regarding the ways in which memory and recall processes affect appraiser accuracy.

Progress: Completed studies include one examining the effect of task salience on appraisal accuracy and behavior recall, and examining the process underlying occupational age-typing and the nature of employee age stereotypes. Additional studies which are currently in progress include an examination of the effects of commitment to an evaluation on the evaluation of new performance information, and a continuing investigation of the processes leading to occupational age-typing.

Potential Applications: (1) the development of a delivery system for performance-appraisal training based on the interactive video system; (2) a set of recommendations for improving real-life performance appraisals.

DECISION MAKING IN DISPERSED, COMPUTER-INTERACTIVE GROUPS

NR 170-965
University of Arizona/Connolly

Scientific Objectives: Investigate the communication networks that develop among multiple decision makers interacting over simple computer-based information channels. It is assumed that network structure will, to an important extent, emerge from user choices, perhaps maladaptively for the decision process overall.

Approach: The project is primarily laboratory-based, empirical research using student participants solving simulated business or other problems. Participants operate interactively on networked microcomputers with on-line data acquisition. The major focus is on the patterns of information exchange that emerge among participants as a function of task demands for coordination, the incentive scheme operating on information suppliers, the cost and quality of the information available, and the size of group performing the task.

Progress: Normative, cost-benefit factors appear to shape acquisition only weakly, and large departures from network optima are typical. The PI is currently exploring the effects of task structure, cueing from other participants, and direct incentives on individual acquisition behavior, with a view to establishing conditions under which emergent networks will develop towards or away from optimal.

Potential Applications: Military operations frequently require decisions to be made by a group of individuals out of range of face-to-face interaction with one another. Command and control systems are designed to support rapid decision making under such conditions. Designers of these systems need to understand the cognitive and interactive preferences that users bring to such networks, since design characteristics can influence decision quality. Furthermore, for reasons either of system malfunction or the need to respond to unique conditions, sometimes users will override a designed system and create an emergent network structure. There is reason to believe that emergent networks may often contain biases which lead to serious mis-matches with the demands of given decision tasks, and a better understanding of these processes could inform the design of future command and control systems.

Reports:

Connolly, T. & Thorn, B. K. (1985): Predecisional information acquisition: Effects of task variables on suboptimal search strategies. (Technical Report #ONR 85-1). Tucson: University of Arizona, August.

THE MINNESOTA INNOVATION RESEARCH PROGRAM

NR 170-966
University of Minnesota/Van de Ven

Scientific Objectives: This research program includes eleven longitudinal studies on the management of a wide variety of technical and administrative innovations. The common research questions being examined in all the studies are: How do innovations develop over time? What organizational arrangements facilitate and inhibit innovation? How do environmental, organizational, group, and individual factors influence innovation success over time?

Approach: The interdisciplinary research group is undertaking a longitudinal study of a set of major innovations, including: Development of galium arsenide integrated circuits, industrial and surgical product innovations, development of complex Naval systems, development of government strategic planning systems, development of vertically-integrated hospital systems, and human resources management innovations. The common research framework being used in all the studies posits that the process of innovation is essentially the evolution of innovative ideas which are carried out by people who are engaged in transactions with others within an institutional setting. Significant changes in these factors represent an event. A careful mapping of events over time is the central common task for all studies in the innovation research program.

Progress: Case histories have been generated for each innovation from its inception to the present, and baseline data have been collected regarding their environmental and organizational settings.

Potential Applications: The longitudinal study of the development of a naval weapons system by Navy contractors will have direct and immediate applications to the Navy. Combined with the other studies, it will contribute to identifying general principles for the management of innovation.

Reports:

Van de Ven, A. H. Leadership and organization culture: navigating the tricky currents (ONR-TR-2). University of Minnesota, The Strategic Management Center, Nov 1984.

Van de Ven, A. H. An examination of alternative forms of fit in contingency theory (ONR-TR-3). Univeristy of Minnesota, The Strategic Management Center, Nov 1984.

Van de Ven, A. H. Dynamics of interorganizational coordination (ONR-TR-4). University of Minnesota, The Strategic Management Center, Nov 1984.

Van de Ven, A. H. The concept of fit in contingency theory (ONR-TR-5). University of Minnesota, The Strategic Management Research Center, Nov 1984.

Van de Ven, A. H. Integrating human resource management and corporate strategy: A preview of the 3M Story (ONR-TR-6). University of Minnesota, The Strategic Management Research Center, Nov 1984.

Van de Ven, A. H. Central problems in the mangement of innovation (ONR-TR-8). University of Minnesota, The Strategic Management Research Center, Nov 1984.

Gresov, R. and Van de Ven, A. Testing the Organizational Assessment Model of Work Unit Design: A Systems Approach (ONR-TR-8). University of Minnesota, The Strategic Management Research Center, Nov 1984.

LEADERSHIP: THEORY AND APPLICATION TO CRISIS MANAGEMENT
NR 170-970
Harvard University/Heifetz

Scientific Objectives: The ultimate aim is the specification of a quantitative theory of group processes involved in leadership phenomena. Intermediate goals are continued expansion of a new set of theoretical principles, and a test of how well these principles are able to model events that occurred during an actual national security crisis.

Approach: Theoretical work will be reflected in a book manuscript. Crisis modeling will be based on analyses of tapes and transcripts (recently released) concerning the Cuban missile crisis. The analysis will focus on one of the central propositions in the theory, viz., that the importance of issues being worked on correlates directly with the strength of avoidance behaviors shown by decision-making participants.

Progress: Work began in late September, 1985 and no Status Reports have yet been received.

Potential Applications: The theory being developed is designed to be especially useful in understanding the leadership of decision-making groups operating under high stress. Effective Navy leadership under such conditions is crucial to Navy's operational readiness.

THE FOLLOWING UNITS WERE COMPLETED DURING THE LAST YEAR

* * * * * *

STRATEGIC MANAGMENT FOR ORGANIZATIONAL EFFECTIVENESS: THE IMPACT OF HUMAN RESOURCE PLANNING ON RETENTION AND RELATED ISSUES
NR 170-949
University of Pennsylvania/Oppenheim

Scientific Objectives: The study explored the relationships among a number of human resource variables which bear upon retention of an appropriate work force. These factors (planning, incentives, mobility and decisions to stay with or leave the organization) were believed to influence the effectiveness of an organization.

Approach: The research took a multi-methodological, interdisciplinary approach to the research problem described above. Specifically, comparative case studies of "exemplar" organizations were used to identify important relationships among the variables listed above. In addition, perceptions of 1) planning and incentive systems, 2) the effect of expectations of mobility on the boss/subordinate interaction and developmental activities, and 3) the effect of organizational signals on the decision to stay with or leave the organization were assessed. Approximately one hundred middle-level personnel from each of six sites were used as respondents. Three instruments were used to collect data: 1) open ended interviews, 2) questionnaire and structured interviews, and 3) scenarios and structured interviews.

Potential Applications: Specific findings can assist human resource policy makers and managers by influencing the incentives, development activities, and communications used to retain an appropriate work force. The Navy can benefit by learning which of its practices correspond to those of the civilian exemplar institutions. This comparison is made easier because a Navy group was used as a research site; differences between the Navy and other sites are thereby elucidated.

Results and Conclusions: The key findings were: 1) a model of job movement which took expectations into account was a good predictor of the way in which a manager and his boss divided tasks; 2) the rate of movement from one job to the next was more rapid in organizations where jobs were clearly and narrowly defined than when jobs evolved and expanded over time; 3) signals from the organization which were public, positive and relevant to a manager's goals increase the likelihood of his remaining with the organization; 4) managers were more likely to see themselves as resource constrained if goal setting and resource allocation were decided at different levels in the organization; 5) informal incentives were more salient to middle managers than most formal incentives.

The results indicated that the strategic considerations of these organizations were well served by their human resource practices although the configuration of policies and practices differed. The research also indicated that these effective organizations exhibited greater flexibility in interpreting policy and enforcing boundaries in areas in which they needed information to innovate and adapt.

Reports:

Oppenheim, L. (1985). Strategic management for organizational effectiveness: The effect of human resource planning on retention and related issues (Final Report). University of Pennsylvania, The Wharton School, Dec 1984.

INCREASING PRODUCTIVITY THROUGH SOCIAL STRUCTURE
NR 170-954
University of North Carolina/Latane

Scientific Objectives: To determine whether negative effects on productivity (termed "social loafing") can be eliminated and reversed by changes in group structure and organization.

Approach: The research consisted of experiments designed to explore the psychological processes underlying social loafing, to discover on what kinds of tasks and in what kinds of job settings it occurs, to find out how it relates to job satisfaction and the quality of work life, and to determine whether the forces leading to social loafing are moderated by cultural background, philosophical or political ideology or personal life history. The research was conducted in the context of a custom-designed, computer-based, telecommunicating ongoing work organization of 100 military-age part-time employees; 20-year olds were hired to work several hours a week for a year in front of computer terminals, communicating with each other and with their supervisors only by machine.

Results and Conclusions: The data indicate that effective group communication can take place in the computer-mediated environment and that anonymity had little effect on either performance quality of patterns of influence, perhaps because of the relative weakness of the identified condition in this research. The data provide evidence for the feasibility of informal interaction and substantial communication of socio-emotional content via computer networks. The data suggest that the computer may not be as poor a medium for this sort of interaction as once supposed. Not the least of the accomplishments has been the development of an ongoing data-collection facility which promises to be a major resource for scientists doing research on individuals working in groups and/or by themselves.

Reports:

Barefoot, John, Wiggins, Beverly and Latane, Bibb (1985). Computer-Administered Panel Study: Methodology (Technical Report). University of North Carolina, Psychology Department.

Barefoot, John, Wiggins, Beverly and Latane, Bibb (1985). Compter-Mediated Communication: Decision-making and Informal Interaction (Technical Report). University of North Carolina, Psychology Department, Feb 1985.

Latane, Bibb (1985). Increasing Productivity through Social Structure: Final Technical Report. University of North Carolina, Psychology Department, Feb 1985.

MANAGEMENT AND WORK FACILITATION: AN APPROACH TO PRODUCTIVITY
NR 170-958
University of Maryland/Schneider & Schoorman

Scientific Objectives: Conceptualization and measurement of work facilitation and management behavior, and establishment of the ways management facilitates and inhibits employee performance.

Approach: The work focused on work groups, not individuals. The goals were the development of generic procedures for diagnosing the presence of unit-level facilitators (and the absence of barriers) as well as management behaviors (e.g., planning, organizing, delegating) that are related to them. The approach began with interviews of work units, moved to development of unit diagnostic-checklists, to administration of the diagnostic checklists to units in a group session. Criterion data for three samples of work units were obtained to allow for inferences about the validity of the diagnostic procedures.

Results and Conclusions: In three different organizations, three versions of a Work Facilitation Diagnostic (WFD) were developed as a basis for differentiating unit functioning within the organizations. Katz and Kahn's conceptualization of subsystem functioning served as the framework for WFD development. In each organization, each work unit completed a WFD and the head of each unit completed a job-analysis survey describing his or her management activities. Criterion data were available on every unit studied (teaching ratings for university departments, sales for telemarketing sales units, and unit ratings of effectiveness for the DoD sample). In all studies some significant relationships were observed between unit WFD data and unit effectiveness suggesting the validity of the procedure used for the development of WFDs.

Potential Applications : The WFD itself is partially, not totally, generic, but the framework and methodology for developing WFDs is totally generic. As such, it is useful for diagnosing a broad range of work units in a variety of organizations. A unique feature of the WFD is its focus on organizational functioning in all of the important subsystems of organizations. A study is now underway, with 6.2 funding, to apply these ideas to a Navy organizational unit (see Cluster I, NR 475-042).

Archival Publications:

Schneider, B. (1985). Organizational behavior. Annual Review of Psychology, 36, 573-611.

Schneider, B., & Bowen, D.E. (1985). Employee and customer perceptions of service in banks: Replication and extension. Journal of Applied Psychology, 70, 423-433.

Schoorman, F.D., & Schneider, B. (1986). Grappling with work facilitation. In F.D. Schoorman and B. Schneider (Eds.), Work facilitation and organizational effectiveness. Lexington, MA: Lexington Books.

Moeller, A., Schneider, B., & Berney, E. (1986). Development, reliability, and validity of the Work Facilitation Diagnostic: Operationalization of the Katz and Kahn subsystem model of organizational effectiveness. In F.D. Schoorman and B. Schneider (Eds.), *Work facilitation and organizational effectiveness.* Lexington, MA: Lexington Books.

PERFORMANCE APPRAISAL: A PROCESS APPROACH

NR 170-961
Purdue University/Ilgen

Scientific Objectives: The objective was to better understand the judgment process by which individuals judge, as accurately as possible, the work performance of others. This judgment practice is very complex psychologically requiring raters to perceive, store, and recall relevant information about others' performance on the job.

Approach: Laboratory and field research investigated the variables that influence accurate judgments. Laboratory research frequently used simulations in which participants role-play supervisors with many tasks, one of which is to conduct performance appraisals. Field research required employees, who do appraisals as part of their job, to view tapes so that accurate raters can be compared to inaccurate ones in order to discover individual and situational differences between the two groups.

Results and Conclusions: The series of research studies showed that cognitive performance-appraisal accuracy was influenced by the nature of the performance of ratees, and more importantly, that cognitive categories influenced performance accuracy. In the latter case, research with nurses developed ways to assess the cognitive categories used by the nurses and to assess the effects of various characteristics of these categories on ratings. Finally, training programs designed to influence appraisal accuracy were found to do so. This work implied that cognitive-process approaches to performance appraisal are useful for explaining some of the factors affecting rating accuracy. However, the amount of variance these factors control in actual appraisal settings may be more limited than initially estimated.

Potential Applications: Results form the basis for improved design of performance appraisal systems and development of training programs for using these systems. Past research has focused almost exclusively on the design of rating scales and training to eliminate rating errors. Our research suggests expansions of approaches to incorporate the way in which raters make interpersonal judgments.

Reports:

Ilgen, D. R. (1985). *Laboratory research: A question of when, not if* (Technical Report No. 85-1). Michigan State University, Departments of Psychology and Management, March 1985.

Kozlowski, S. W. J., Kirsch, M. P., & Chao, G. T. (1985). *Job knowledge, ratee familarity, conceptual similarity, and halo error: An exploration* (Technical Report No. 85-2) Michigan State University, Departments of Psychology and Management.

Ilgen, D. R., & Wiggins, A. (1985). *The passage of time: A neglected factor in the goal setting-to-performance to-feedback sequence* (Technical Report No. 85-3) Michigan State University, Departments of Psychology and Management, August 1985.

Archival Publications:

Ilgen, D. R., & Favero, J. L. (1985). Methodological limitations of social psychological literatures for the understanding of performance appraisal processes. *Academy of Management Review, 10*, 311-321.

I. SPECIAL PROJECT: MANPOWER R&D PROGRAMS

This is an interdisciplinary program of exploratory development managed by Dr. Stan Collyer in the ONR Technology Programs Directorate. Scientific Officers for these contracts are located in the Psychological Sciences Division and the Mathematics Program of the Office of Naval Research. This brochure includes descriptions only for those contracts monitored by a Scientific Officer in the Psychological Sciences Division.

The program was initiated as a direct result of the national policy that replaced the draft with the all-volunteer force as the source of defense manpower. The ONR manpower program has dealt with a wide range of programs, both in response to, and in anticipation of, expressed Navy needs. A major aim has been the development of techniques and models to be used by Navy and Marine Corps managers in dealing with manpower and personnel issues. Research is conducted in universities and other institutions; methods are varied and include experimentation, statistical analysis, simulation, and modeling. This program is closely coupled with the operating arms of the Navy and Marine Corps through the mechanism of a planning committee, whose members include ONR Scientific Officers, the Naval Civilian Personnel Command, the Naval Military Personnel Command, the Navy Recruiting Command, the Navy Personnel Research and Development Center, several directorates in the Office of the Chief of Naval Operations, and the Navy Secretariat.

During the year reported on herein, the research focused on development of reenlistment decision aids, factors that facilitate work performance, and new concepts and techniques for assessing military personnel effectiveness.

MANPOWER RESEARCH AND ADVISORY SERVICES
NR 170-032
Smithsonian Institution/Sinaiko

Scientific Objectives: The contract serves as a bridging mechanism for naval manpower issues and the research that addresses them. Substantive areas include: the retention of skilled personnel, the supply of manpower to the Navy, personnel turnover, and the reserve force. The contract also arranges for the services of expert consultants in the behavioral sciences.

Approach: Provides for information exchange through a navywide committee. Develops new data bases on specific issues, (e.g., occupational correlates of personnel attrition) and conducts statistical analyses on them. Chairs an active international collaboration among military manpower researchers in the U. S., Canada, Australia, New Zealand, and the United Kingdom.

Progress: Special symposia and meetings have been planned and conducted on such subjects as personnel supply forecasting, recruiting advertising effectiveness, and innovations in survey research methodology. In 1985, for example, a workshop on Hispanic personnel was organized.

Potential Applications: Information about new research and about innovative manpower practices and policies, acquired through inter-service (U.S.) and international collaboration and exchange, reaches the U.S. Navy through the Manpower R&D Planning Committee. Subjects include but are not limited to career information, retraining, expanding the supply of manpower, and new ability measures, both cognitive and non-cognitive.

Reports:

Sinaiko, H. W., Curran, P. M. King, B. T., & Schneider, J. M. (1985). Hispanic Subpopulations and naval service (Tech. Rep. SI/MRAS/TR-11). Smithsonian Institution. (AD-A154662).

Sinaiko, H. W. (1985). Part-time soldiers, sailors, and airmen: Reserve force manpower in Australia, Canada, New Zealand, the UK, and the U.S. (Tech. Rep.). The Technical Cooperation Program.

Archival Publications:

Sinaiko, H. W. (1985). European psychology and the Office of Naval Research. American Psychologist, 40, 861-862.

THE DRILL INSTRUCTOR: STRESS, COPING SKILLS, AND CAREER DEVELOPMENT

NR 475-009
University of Washington/Sarason

Scientific Objectives: To develop and evaluate a unified program dealing with stress-coping skills for both the Marine Corp Recruit Depot, San Diego, and the Marine Corp Recruit Depot, Parris Island. The aim of the project is to produce relevant televised modules and ancillary material, and to conduct an evaluation of all materials.

Approach: The project has several components. One of these is the production of televised modules and vignettes for use as part of the Drill Instructor School curriculum. Manuals for use by Drill Instructor School instructors and a study guide for Drill Instructor School students will be developed. All of these materials will be evaluated using objective and subjective indices.

Progress: The televised modules and vignettes and will be completed by the end of 1985. The program will then be evaluated.

Potential Applications: The materials developed should be of considerable value in strengthening the stress coping skills of drill instructors. This should result in improvements in the drill instructors' performance and the effectiveness of the recruits they train.

Funding: USMC

AN AUTOMATED AID FOR PERSONNEL RETENTION

NR 475-014
University of Washington/Beach & Christensen-Szalanski

Scientific Objectives: (1) to develop a technique for identifying personnel who are up for re-enlistment who a) clearly are going to re-enlist, or b) who clearly are not going to re-enlist, or c) who are undecided, and (2) to develop a video/computer system for helping them think through their re-enlistment decision. The system serves to identify the three groups, and pinpoints for the third group those areas of concern that may be addressed in career counseling. The counseling consists of supplying relevant information in an attempt to aid in clarification of the decision.

Approach: The system uses simplified multi-attribute utility theory (MAUT) for a hierarchically organized set of categories of considerations that have been obtained in face-to-face interviews with personnel from submarine, air, surface, and shore commands. The MAUT hierarchy is presented via computer and detailed instructions are keyed to the presentation using a laser-beam videodisc recording of the step-by-step procedure.

Progress: Interviews have been completed, the hierarchy has been constructed and has been reviewed by experienced Naval career counselors for relevance and authenticity, videorecording has begun, the computer/video hardware has been assembled, and programming is nearly completed. It is expected that the system will be ready for installation in a command for initial testing early in 1985.

Potential Applications: This system will enable the Navy to ascertain what factors are most important in reenlistment decisions, and will help potential reenlistors to more carefully think through their decisions.

Reports:

Christensen-Szalanski, J. J., Northcraft, G. B. Patient Compliance Behavior: The Effects of Time on Patients' Values of Treatment Regimens (TR-85-1). University of Washington, Department of Psychology, March, 1985.

Beach, L. R., Weinstein, B. L. & Christensen-Szalanski, J. J. U.S. Navy Reenlistment Decision Aiding Scheme. (TR-85-2). University of Washington, Department of Psychology, March, 1985.

MARGINAL-MAXIMUM-LIKELIHOOD ESTIMATION IN ITEM-RESPONSE THEORY.
NR 475-018
National Opinion Research Center/Bock

Scientific Objectives: In this work, the usefulness of recent theoretical developments in marginal-maximum-likelihood methods for estimating item-response functions, for gauging the dimensionality of tests, for simultaneous multidimensional adaptive testing, and for estimating the trait distributions of selected subpopulations were explored in a military context.

Approach: Empirical studies employing Armed Services Vocational Aptitude Battery (ASVAB) data from the Profile of American Youth were used. The investigator developed a full-information factor analysis of the data and examined the performance of various indices of the number of factors. Three-parameter logistic models were fit to all 10 ASVAB subtests and cross-validated. Estimated item-information functions were examined in light of item content and evidence for multidimensionality. Several methods for estimating subtest trait distributions were also examined and compared.

Results and Conclusions: (a) A four-phase Bayes constrained estimation procedure has extended Bock's earlier work to the three-parameter-logistic situation. These procedures have been successfully applied to the Profile of American Youth data set. (b) Analysis of the dimensionality issue suggested that the Auto-Shop subtest is two-dimensional. (c) A multiple-category model for incorporating information from wrong responses to multiple-choice items has been developed and tried out with the ASVAB data set.

Potential Applications: (a) The multiple category model makes possible the recovery of information available in wrong responses to multiple-choice test items and can thus increase the speed and accuracy of computerized adaptive testing. The model also provides so-called category operating characteristics. These functions can be used by test designers to assess the effectiveness of distractors in multiple-choice test items. (b) The full-information factor analysis developed in this work ought to replace traditional linear factor analysis. The full-information approach not only conforms more closely to the latent-trait non-linear notion of dimensionality, but also reduces the likelihood of obtaining spurious guessing factors.

Funding: ONR Manpower R&D Program.

Reports:

Bock, R. D., Gibbons, R., & Muraki, E (1985). Full-information item factor analysis (Technical Report 85-1). Chicago, IL: National Opinion Research Center, University of Chicago.

Mislevy, R. J. & Bock, R. D. (1984). Item operating characteristics of the Armed Services Vocational Aptitude Battery (ASVAB), form 8A (Technical Report). Chicago, IL: National Opinion Research Center, University of Chicago,

Thissen, D. & Steinberg, L. (1984). A response model for multiple choice items (Technical Report). Chicago, IL: National Opinion Research Center, University of Chicago.

Archival Publications:

Mislevy, R. J. (1984). Estimating latent distributions. Psychometrika, 49, 359-381.

Thissen, D. & Steinberg, L. (1984). A response model for multiple choice items. Psychometrika, 49, 501-519.

EVALUATION AND IMPROVEMENT OF TEAM EFFECTIVENESS IN ANTI-SUBMARINE WARFARE COMBAT EXERCISES

NR 475-026
Georgia Institute of Technology/James

Scientific Objectives: (1) Develop empirically validated causal model of Anti-Submarine Warfare (ASW) team effectiveness; (2) develop empirically validated causal models of the processes through which the effectiveness of teams determines the performance of multi-team "Units" of ships and aircraft operating in coordinated combat exercises.

Approach: Data on unit effectiveness, team effectiveness, and causes of performance effectiveness are being collected at the ASW Training Center, Pacific during simulated scenarios in which the Unit's task is to locate and destroy enemy submarines. Primary sources of data are effectiveness evaluations furnished by ASW instructors through behavioral ratings and reports on causes of team effectiveness (e.g., communication, manning/staffing, motivation, leadership, stress, team cohesiveness and morale) from team members and ASW instructors via questionnaires. Empirically validated models are being constructed using confirmatory-analytic and time-series-analytic procedures.

Progress: Progress includes the development and administration of team readiness questionnaires, the construction of the criterion rating form now being completed by ASW instructors for each graded exericse, the formulation of additional instruments to assess psychological variables not addressed in the rating form, the creation of a macro, unit-level measure of performance, and the development of causal models which hypothesize the determinants of team performance and, perhaps more importantly, specify the causes of overall unit performance in terms of particular aspects of individual team effectiveness. Of special interest in empirically validating these models is the new criterion rating form used by the ASW instructor to rate team performance. Based on a highly detailed, behaviorally-oriented, contact-by-contact task analysis, this criterion rating form serves as the final grade sheet for ASW teams. In addition, it serves as a measure of the team-level process variables which contribute to unit level effectiveness.

Potential Applications: The empirically validated causal models of team and unit effectiveness generated through this research will be translated into useful products for ASW training by (a) developing training modules for ASW tactical decision-making, (b) contributing to the design of computer simulations for shipboard and off-site, shore-based ASW team training, and (c) constructing indicators for assessing team readiness.

Reports:

James, L. R., and Tetrick, L. E. (1984). Confirmatory analytic tests of three causal models relating job perceptions to job satisfaction (Tech. Report GT-ONR-6). Georgia Institute of Technology, Psychology Department, December 1985.

James, L. R., Demaree, R. G., and Mulaik, (1985). S. A. A note on validity generalization procedures (Tech. Report GT-ONR-7). Georga Institute of Technology, Psychology Department, January 1985.

Archival Publications:

James, L. R., and Tetrick, L. E. (1986). Confirmatory analytic tests of three causal models relating job perceptions to job satisfaction. Journal of Applied Psychology 71, 77-82.

PREDICTING MILITARY PERFORMANCE FROM EDUCATIONAL AND BIOGRAPHICAL INFORMATION

NR 475-027
Human Resources Research Organization/Reigelhaupt

Scientific Objectives: In previous work the investigators developed a survey instrument known as the Educational and Biographical Information Survey (EBIS) and administered it to large numbers of military applicants and recruits. This project is cross-validating EBIS items previously found to be the best predictors of 6-month attrition with attrition experience at 12 & 24 months, with pay-grade data at 30 months and with reenlistment recommendations/decisions.

Approach: By linking EBIS response data to Defense Manpower Data Center (DMDC) records, investigators are identifying EBIS respondents' attrition status at 6, 12, & 24 months, their pay grade at 20 months, and reenlistment recommendations/decisions. Covariance matrices for predictor and criterion variables are being examined and discriminant/regression analyses are being performed to identify the types of biographical information which significantly improve predictions of military performance. All analyses are being made both for the total DoD accessions and for individual Service accessions.

Progress: A detailed comparison of data on the performance of EBIS and a variety of Service and DoD biographical inventories have been completed. Analyses indicated that items dealing with school behavior and attitudes are most consistently effective. In other work the predictive ability of various indices of past behavioral difficulties was compared: Defense Central Index of Investigation (DCII) status, moral waiver status, EBIS self report arrest scale score, and EBIS self report drug/alcohol scale score. Of these all except moral waiver status were found to be statistically related to attrition during the first 12 months of service.

Potential Applications: This project is part of a multiple agency effort aimed at developing a pool of validated items from which the Services can draw questions for military candidate screening instruments to supplement cognitive measures such as ASVAB.

Reports:

Laurence, J.H. & Means, B. (1985). A description and comparison of biographical inventories for military selection (Technical Report FR-PRD-85-5). Alexandria, VA: Human Resources Research Organization.

EFFECTS OF JOINT SERVICE ADVERTISING ON RECRUITMENT OF MILITARY PERSONNEL

NR 475-029
University of Pennsylvania/Carroll

Scientific Objectives: Assess the hypothesis that the same recruitment effectiveness can be achieved by increasing the Joint Service Advertising budget significantly while decreasing the overall DoD Active Enlisted NPS (Non-prior Service) Recruitment advertising budget.

Approach: An experimental design was developed for implementation in the field which would entail testing two advertising dimensions simultaneously: The level of the total DoD Active Enlisted NPS recruitment advertising budget, including both Joint and Service-specific and the mix of joint and service-specific advertising within each total advertising expenditure level. The field test currently underway includes combinations of total advertising budgets (i.e., current, higher, and lower) and various proportions of that budget dedicated to Joint advertising (i.e., low, current, and high).

Progress: The complex and unique advertising data base which this effort set out to develop is virtually complete. The criterion measures have shown both predictive validity and appropriate statistical sensitivity.

Potential Applications: This research will provide the scientific foundation for decisions on military advertising budgets by the Secretary of Defense.

Funding: Assistant Secretary of Defense (Manpower)

FAMILY STRESS AND COPING DURING ROUTINE DEPLOYMENT
NR 475-031
Mental Research Institute/Coyne and Nelson

Scientific Objectives: To understand stress and coping processes in families affected by the routine deployment of patrol aviation squadrons in terms of the psychological, social, and somatic health of members. To provide the foundation for an empirically based, multivariate model of family adaptation to deployment and its relationship to service personnel's performance and retention.

Approach: This longitudinal study involves repeated questionnaire assessments of 120 families across each of the three phases of deployment. Extensive use is made of data concerning individual and family functioning. These include measures of stress, coping, psychological resources, informal social support and utilization of formal services, and adaptational outcomes, which are related to families' attitudes toward the military and to the servicemember's evaluations and fitness reports and recommendations for promotion. Additionally, these quantitative data are being supplemented with qualitative data derived from focus groups conducted with service members and their spouses.

Progress: All instruments have been developed, pilot tested, and refined, and are now in final form. Data collection is continuing, data are being entered as received, and codebooks have been developed. Preliminary analyses with data from the first waves of assessments have begun, utilizing a multiple regression approach to predict satisfaction with military life, morale, and commitment to reenlistment from stress and coping variables. The focus groups are currently being conducted.

Potential Applications: Successful completion of this research will give the Navy an empirical data base for programs designed to improve organizational readiness before, during, and after deployment. Predictors of readiness, morale, and commitment to reenlistment be identified, along with sources of individual and family vulnerability and strengths.

EFFECTS OF DEPLOYMENT ON PERFORMANCE
NR 475-032
Eastern Virginia Medical Authority/Archer

Scientific Objectives: To identify psychosocial responses to deployment procedures among Navy personnel and their dependents and relate individual and familial response patterns to performance efficiency and effectiveness for active duty personnel.

Approach: A randomly selected group of 3,500 active duty Navy personnel and their dependents is being examined during defined periods of deployment and non-deployment in a cross-sectional and longitudinal approach utilizing a quasi-experimental design. Data are being gathered across diverse areas of adjustment including personality functioning, cognitive functioning, social support network characteristics, academic and work performance.

Progress: Collection has been completed of pilot data on about 400 Navy personnel and 200 spouses, with a questionnaire return rate of about 50%. These data are being analyzed and a preliminary progress report is being prepared.

Potential Applications: This research will relate empirical measurements of the rate of occurrence of problematic response patterns to deployment procedures and will develop a check list of characteristics of those families who are most at risk for psychosocial stress response and maladaptive functioning in response to deployment procedures.

US MARINE CORPS JOB PERFORMANCE
NR 475-036
Texas A&M/Fisher

Scientific Objectives: The focus in this research is on understanding the cognitive processes by which raters receive, store, recall, and integrate information about the job performance of others, and about how individuals self-regulate their behavior based on goal-setting and feedback to them from the environment on their past performance. Categorization of a person, behavior, situation or object is thought to be the outcome of a feature-matching process, in which a stimulus is compared with the features of a category "prototype". Once categorization has occurred, the information about the stimulus is cognitively integrated with the relevant category prototype, and in making subsequent judgements observers are hypothesized to rely heavily on the prototype. Based on these theoretical notions, new performance evaluation systems will be designed for the Marine Corps along with new systems for training supervisors to make better evaluations.

Approach: Marine Corps will define the dimensions on which they wish to have people assessed, and PIs will apply their theoretical notions to developing job-relevant category prototypes. The key is identifying those behaviors which can be considered prototypical for a given location on a dimension. This is done by first generating a list of relevant behaviors, then separately rating the prototypicality of each behavior. Out of initial long lists, only those anchoring definitions are retained which are judged to have high prototypicality. These consensus prototypes then become the basis for training of performance evaluators.

Progress: This work was begun late in FY 85, and no Status Reports have yet been issued.

Potential Applications: Literature on performance appraisal indicates that an improved formal feedback system can result in performance gains of 10 to 30%. The Marine Corps is presently revising its performance appraisal system, and this effort is expected to contribute to that revision.

Funding: ONR, USMC

LONG TERM ORGANIZATIONAL EFFECTS IN NAVY UNITS
NR 475-037
Rensis Likert Associates/Bowers

Scientific Objectives: This project builds upon earlier work (NR 475-010) which suggested that a ship's culture changes slowly and has a long-term impact on performance (even where there has been complete turnover of personnel). The goal of this project is to examine these "constancy" effects in conjunction with the effects of "personnel velocity" (rate at which new recruits move through the system). The work will augment an already substantial data set and will test a proposed explanation for this long-term impact.

Approach: The method of study involves five steps: (1) develop and validate objective indicators of personnel velocity; (2) develop and validate objective indicators of individual vulnerability to Project Upgrade actions and of psychological and physical escape from a given job situation; (3) collect and classify information on discrete events involving each ship studied; (4) test the main effects and moderating effects implicit in the constancy-velocity model; and (5) calculate the impact of these effects on Upgrade discharges and other performance measures.

Progress: Work on this project began late in FY-85 and no Status Reports have yet been received.

Potential Applications: The earlier findings cited suggest that evaluations of ship and crew performance may be systematically overlooking a potent determinant (long-term culture effects), which should be understood and taken into account. There are implications for management practices, for human resource accounting, and for career planning and development.

PREGNANCY ATTRITION AMONG WOMEN MARINES
NR 475-039
Iowa State University/Gerrard

Scientific Objectives: This study is designed to determine the antecedents of both pregnancy and pregnancy attrition among first-term women Marines, and to apply these findings toward future policy-making aimed at reducing pregnancy attrition in this population. Data obtained from Marines will be put in the perspective of similar data collected from large numbers of civilian women in the same age group.

Approach: 800-1000 first-term women Marines will be surveyed during recruit training, and then again six, twelve, and eighteen months later, with a survey instrument covering sexual and contraceptive behavior as well as attitudes and knowledge necessary for effective contraception. Comparison groups of college women will also complete the survey at about the same time to control for variations in cohorts over time. Multidimensional contingency table analysis, regression analysis, and multivariate analysis of variance will be used to determine the relative contributions of a number of variables to effectiveness of contraception and to pregnancy attrition.

Progress: This work was begun late in FY-85, and no Status Reports have yet been received.

Potential Applications: The first-term attrition rate among women Marines is close to 50%, and more than half of this attrition is due to pregnancy. The Marine Corps is actively seeking information to guide efforts to design interventions to reduce this rate.

Funding: USMC

ARTIFICIAL INTELLIGENCE RESEARCH IN NAVY PERSONNEL ASSIGNMENT
NR 475-041
The Turing Institute/Niblett

Scientific Objectives: The aim is to produce an expert system which can acquire information by generalization from expert-supplied examples, and which can provide overall system control functions for a large-scale personnel assignment system.

Approach: A logic programming framework is being used to design, test, and implement structure induction methods for the acquisition of expert, rule-based knowledge about personnel assignment procedures. These automated induction methods will be used to acquire a knowledge-base of decision rules and procedures directly from an examination of expert behavior. This knowledge-base will form an integral part of an intelligent control system for a large-scale personnel assignment/distribution system.

Progress: This work began late in 1985, and no Status Reports have been issued as yet.

Potential Applications: The expert system will interface to an existing system, based on operations-research methods, which is being implemented and tested at the Navy Personnel R&D Center. More generally, the method of structured induction can be applied to the problem of automatically acquiring an expert knowledge-based in any well-defined domain.

Funding: Manpower Committee

WORK FACILITATION
NR 475-042
University of Maryland/Schneider

Scientific Objectives: This project is a transition to a 6.2 effort of work that was carried out under a 6.1 contract (NR 170-958). The earlier work was concerned with conceptualizing and measuring the ways in which management behavior facilitates or inhibits employee performance. The model of work unit effectiveness developed will now be applied to a Navy environment (OP-OI), and data collected there will be compared with similar kinds of data from civilian organizations for an improved perspective on both.

Approach: Data collection begins with interview and observational techniques to identify the important categories of managerial activities and organizational practices in the organizational unit. From these first results survey methods are developed and tested for reliability and validity. Unit members then respond to the survey, and results are analyzed with multivariate techniques to test for relationships hypothesized by the model.

Progress: This work began late in FY-85, and no Status Reports have yet been received.

Potential Applications: Findings will provide a technological base for a new system to provide Navy managers with information and recommendations potentially useful for enhancing work unit effectiveness.

DEVELOPMENT OF COMPUTER-BASED INSTRUCTIONAL SYSTEMS FOR TRAINING ESSENTIAL COMPONENTS OF READING
NR 154-519
BBN Laboratories/Frederickson

Scientific Objectives: The objective is to develop and evaluate instructional methods for training critical components of reading skill. Computer-based instruction incorporates continuous dynamic monitoring and feedback to develop and automate efficient decoding and comprehension procedures. A final objective is to extend interactive reading theory to include the high-level skills needed for analyzing cohesive features of text.

Approach: The instructional approach follows an analysis of reading in terms of skill components that are functionally interrelated. Components selected for training are those that have a broad impact on reading performance and that present particular problems for low-ability adult readers. Training is component-specific, including immediate feedback on efficiency and accuracy of performance. Where there are hierarchical interactions among components, training of lower-order components precedes training of higher-order components, and integration of skills is explicitly built into the later learning exercises.

Progress: Based on related research on controlled vs. automatic components of cognitive skill, computer-based systems have been developed for training reading-skill components in low-ability adult readers. These training systems incorporate advanced graphics, synthesized speech, and individualized instructional monitoring. Graphic feedback on performance and progress is a central design feature. Experimental evaluations of the training systems have been used to improve their design, as well as to gain more detailed knowledge of the structure and acquisition of reading skills.

Potential Applications: The instructional methods developed will be useful in remedial training programs, and can also be applied in any area of training in which automaticity of skill components is essential to effective high-level performance.

Funding: NPRDC, Manpower R&D Programs.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

AN AUGMENTED COMPUTERIZED READABILITY EDITING SYSTEM
NR 667-513
University of Arizona/Kieras

Scientific Objectives: The objective was to use existing psycholinguistic data to develop principles for the design of an automated text-analysis system. The system should be able to critique and suggest revisions for a typical range of technical text.

Approach: The research plan combined an extensive analysis of the existing literature in psycholinguistics with natural language comprehension methods derived from artificial intelligence research. The combination of these two approaches yielded a principled design for an automated technical writer's aid that incorporates a deeper understanding of comprehension and natural language structure than do conventional writers' aids.

Results & Conclusions: A large number of psycholinguistics articles were summarized and an initial set of comprehensibility rules was devised. An experiment was improved by using these rules. A demonstration version of the comprehensibility system was constructed using components from earlier comprehension models. The demonstration system was able to make many useful comments about maintaining coherence and consistent terminology.

Potential Applications: Development of an actual usable system to improve the content of technical material.

Reports:

Kieras, D.E. (1985). The potential for advances computerized aids for comprehensible writing of technical documents (TR-85/ONR-17). University of Michigan, Psychology Department.

Kieras, D.E. (1985). Improving the comprehensibility of a simulated technical manual (TR-85/ONR-20). Univerrsity of Michigan, Psychology Department.

Kieras, D.E., & Dechert, Christiane. (1985). Rules for Comprehensible Technical Prose: A survey of the Psycholinguistic Literature, (TR-85/ONR-21). University of Michigan, Psychology Department.

Kieras, D.E. (1985). An augmented computerized readability editing system: Final report (TR-85/ONR). University of Michigan, Psychology Department.

EMPIRICAL STUDY TO ENHANCE THE REENLISTMENT PROCESS OF CIVILIAN PERSONNEL WITH PRIOR MILITARY SERVICE
NR 475-003
Pennsylvania State University/Stephenson

Scientific Objectives: The project is designed to clarify the reenlistment process of prior-service personnel. The first objective is to utilize a market segmentation model to compare and contrast background factors and the behavior of new recruits and re-entrants. The second objective is to model determinants of relative wage growth, job performance, and time in and out of the military.

Approach: Several methodological approaches were used, including discriminant analysis, multiple regression analysis, survival analysis, and contingency table analysis. In general, the researchers seek to understand how economic, demographic, and military characteristics contribute to an individual's being a re-entrant, leaver, or stayer, and secondly, to understand how selected behaviors compare among groups.

Results and Conclusions: This project generated multivariate predictive models of subgroup membership. Policy conclusions can be inferred from these results. For instance, some analysts have viewed prior-service personnel as a solution to manning shortages in critical occupations. Contrary to this view, the findings suggest that only a few prior-service individuals are desirable recruits based on how long they stay once they reenter and how many leave for adverse behavioral reasons.

Potential Applications: Results from this study have been briefed extensively to appropriate Navy offices, e.g., Chief of Naval Personnel, and have led to a number of reenlistment policy changes, all based on empirical findings.

Report:

Stephenson, S. P., Mitchell, M.E., Beik, L. L., Macpherson, D. A., Fitch, S. D. & Ellison, D. R. (1985) An empirical study to enhance the reenlistment process of civilian personnel with prior military service (TR-ONR-85-1). Pennsylvania State University, Institute for Policy Research and Evaluation.

IMPROVING THE EFFECTIVENESS OF NAVAL RECRUITING EXPENDITURES FOR QUALITY ENLISTMENTS

NR 475-004
Duke University/Morey

Scientific Objectives: To improve the budget building (POM) process where monies for recruiter field level support and Navy specific advertising must be defended, given enlistment objectives, number of recruiters to be made available, the prospective recruiting environment, and the level of DoD Joint Advertising. The capability for performing extensive sensitivity analyses on the budget, needed as various of the above considerations are varied, was also highly desired. Also of interest were improved enlistment goal-setting and recruiter-allocation procedures.

Approach: Econometric models which take advantage of natural variations in support level per recruiters, number and location of recruiters, advertising, etc. were used to estimate key elasticities. These models were first validated on separate years of data to establish their reasonableness and credibility. Then the resulting budget generation formulae were programmed for an IBM-PC.

Results & Conclusions: A fully tested and documented IBM-PC program was installed at Naval Recruiting Command Headquarters, complete with user's manuals and examples. In exercising the program for recent years, the program gave results within a few percent of that actually spent. In addition to providing the ideal tradeoff between recruiter support and advertising (by area by quarter), the program is capable of handling contract goal-setting and geographical recruiter allocation in several different fashions.

Finally by incorporating the pay for recruiters it can help determine the cost-effective number of recruiters that should be made available.

Potential Application: The program can quickly perform sensitivity and "what-if" type analysis. A host of scenarios can be analyzed, e.g., pessimistic and optimistic forecasts of the unemployment rate, contract objectives, etc. The program can analyze impacts of changes in military pay versus civilian pay.

Report:

Morey, R. (1985). Trading off recruiter field level support versus advertising: A budget building model incorporating Optimized recruiter allocation and contract goaling (Technical Report ONR-389-2), Duke University, Fuqua School of Business, April 1985.

Archival Publication:

Morey, R. (1985). Managing the Armed Services Delayed Entry Pools to Improve Productivity in Recruiting, Interfaces, 15 (Sep./Oct.).

TRANSITION SOCIALIZATION EFFECTIVENESS IN ORGANIZATIONS
NR 475-019
Texas A&M University/Fisher

Scientific Objectives: To increase our understanding of the socialization and adjustment processes that occur during job transfer.

Approach: Approximately 150 NCOs participated in the primary research project. All were interviewed prior to moving, and were surveyed three months after arriving at their new location. Most previous transfer research has been cross-sectional and retrospective in nature, whereas the present study is longitudinal and predictive. Dependent variables to be predicted were post-transfer performance, adjustment, and attitudes. Independent variables include transfer history (number and frequency of moves), family size and age variables, cost of the move, subjective difference between old and new locations ("contrast"), realism of pre-move expectations ("surprise"), and job/career variables.

Results and Conclusion: Post-move adjustment indices were found to be predicted by pre-move attitudes toward the move, adjustment and satisfaction with previous moves, number of dependents, unmet expectations, perceived job advancement, and amount of information about the new location received prior to moving. Time to "get up to speed" in a new job and both performance and role ambiquity three months after moving were strongly predicted by the similarity between the old and new jobs.

Potential Applications: The research suggests that transfers will be more successful if transferees perceive the move as a job or career advancement, develop positive expectations before the move, and are supplied with information about the new job and location prior to moving. When individuals are transferred to dissimilar jobs, they should remain in the assignment several months longer than usual in order to maintain the same ratio of learning time to productive time as is realized when transferring between similar jobs.

Reports:

Shaw, J. B., Fisher, C. D., and Woodman, R. W.(1985). Predictors of transfer adjustment: A longitudinal study (TR-ONR-7). Texas A&M University, Department of Management, January 1985.

Jones, G. R. and Fisher, C. D. (1985). The relationship between performance and satisfaction: A utility analysis (TR-ONR-8). Texas A&M University, Department of Management, March 1985.

Shaw, J.B., Fisher, C.D., and Woodman, R.W. (1985). Making a transfer: An analysis of qualitative data relevant to tranfer attitudes and adjustment (TR-ONR-9). Texas A&M University, Department of Management, June 1985.

Fisher, C.D., Shaw, J.B., and Woodman, R.W. (1985). Final report on transition socialization effectiveness: Year three (TR-ONR-10). Texas A&M University, Department of Management.

PERSONNEL AND TRAINING RESEARCH PROGRAMS

(CLUSTERS J-M)

The Personnel and Training Research Programs support research which will enable the naval services to more efficiently acquire, train, and use personnel. To this end our research efforts are focused on methods for assessing people's potential and competence and for conducting rapid, efficient training. Two considerations guide our effort. First, it appears that the best opportunities for increasing the efficiency of assessment and training lie in individualizing (usually using computers) each process to each individual. Second, the increasingly technological character of many aptitudes should receive major emphasis. These considerations have led us to support research on objective, quantifiable theories of cognition and information-processing performance of the types required on Navy jobs. Naturally, much of the same research is also concerned with the methodologies needed to exploit these theories for the purposes of assessing individuals' cognitive aptitudes and competencies, and improving those competencies through training. The work on those theories and methodologies falls into four main clusters.

J. Theory-based Personnel Assessment. Research in theory-based personnel assessment should lead to more efficient and valid psychological assessments for improving the Navy's selection, classification, advancement, and training functions.

K. Information-Processing Abilities, Attention and Action. Exploration of individual differences in the basic parameters of information processing is aimed at a clearer understanding of aptitudes and other abilities important in Navy jobs.

L. Instructional Methods and Technology. This work on instructional theories looks to eventual application in generative, knowledge-based, automated systems for training cognitive skills, and to improved methods for developing and evaluating training materials.

M. Cognitive Processing. This last cluster is aimed at models of the cognitive processes and structures underlying skilled performance in real-world tasks with complex information-processing demands.

J. THEORY-BASED PERSONNEL ASSESSMENT

The measurement of individual differences is an indispensable part of psychological research, both theoretical and applied. It is the main source of data in studies of the evolution of both cognitive and non-cognitive competence and performance and in other areas of psychology which seek to explain individual behavior. It is the basis for the Navy's personnel selection and classification technology, for career counseling, for the design of instructional interventions, and for performance evaluation. Its role is central whenever a case-by-case approach is taken to personnel decisions and to behavioral, instructional, and performance-aiding interventions of all kinds. The primary impact of the work described in this cluster it to enhance the accuracy, efficiency, validity, and scope of the measurement of individual differences.

Work in this cluster is attacking fundamental measurement issues form a variety of perspectives, including: (a) theoretical development of the measurement foundations, (b) mathematical and numerical development of modelling techniques, and (c) experimental and simulation studies of assess model adequacy. Work is focused on developing and extending item-response theory, a powerful unified framework for relating behavior to unobservable traits. Within this framework rigorous mathematical formulations are being developed for assessing whether two measurement paradigms are measuring the same psychological trait(s), for discovering the shapes of item-response functions without strong *a priori* shape constraints, for modelling behavior on groups of tasks which fail to be conditionally independent, for calibrating item-response functions from the sparse data available during operational test, and for identifying examinees for whom the models fail to fit.

Collaboration among investigators in this cluster, and coordination with other agencies, is extensive. Four work units involve collaboration among researchers at multiple institutions. ONR holds is a member of the Computerized Adaptive Testing/Armed Services Vocational Aptitude Battery (CAT-ASVAB) Working Group. In direct support of CAT-ASVAB Working Group mission, one work unit (NR 4421-520), jointly funded with AFHRL, NPRDC, MEPCOM, and OASD(M&RA) is exploring techniques for the calibration of item-response functions on-line during computerized adaptive testing. In support of Navy and Marine Corps training, two work units (NR 4421-495 & 4422-531) are establishing research laboratories in Navy and Marine Corps schools as test beds for model-based measurement concepts. We also hold annual contractors' meetings focusing on model-based measurement issues. These meetings typically attract all of the leading contributors to model-based measurement and include representatives of other Navy, DoD, and civilian federal agencies. These meetings serve to foster mutual exchange of recent insights and research results.

LATENT-TRAIT THEORY FOR DISCRETE-RESPONSE MODELS
NR 150-467
University of Tennessee/Samejima

Scientific Objectives: This work builds upon Samejima's earlier research on function estimation for nominal, graded, and continuous responses, and for multi-dimensional latent spaces. The current work has three major components: (a) further refinement and evaluation of methods for estimating response-category operating characteristics for multiple-choice items; (b) theoretical, statistical, and numerical development of a class of models to replace existing three-parameter models for multiple-choice tests; and (c) structuring of the field and the preparation of integrated written materials and computer programs which make recent develoments useable for applications.

Approach: Refinements of two estimation procedures are being explored. Methods are being sought which maintain the richness of the class of admissible functions and minimize estimation instability. Further theoretical development of Samejima's model for multiple-choice test items is focusing upon the rationale for assessing item and distractor quality and on techniques for combining categories when needed. In other work, easily useable computer programs which implement theoretical results are being developed.

Progress: Results suggest that the methods and approaches that have been developed and modified in this research for estimating the operating characteristics of discrete responses work well. The operating characteristics of the wrong alternative answers of multiple-choice test items, which are named plausibility functions. Many of them turned out to be quite informative. In other work, the effect of assuming the three-parameter logistic model for simulated data which actually follow the (two-parameter normal) given model was investigated. Results clarified its extent of danger and tolerance.

Potential Applications: This work is providing theoretical underpinnings for the following applications: (a) investigating the shapes of item-response functions, (b) on-line calibration of new test items from the data collected during operational tests, (c) vertical equating of tests intended for broad-range tests, (d) systematic analysis of the quality of distractors on multiple-choice test items, and (e) modelling response data which includes both continuous and discrete aspects.

Reports:

Samejima, F. (1985) Plausibility functions of Iowa vocabulary test items estimated by the simple sum procedure of the conditional pdf approach (Technical Report ONR-84-1). Knoxville, TN: University of Tennessee, Department of Psychology. December, 1984.

Samejima, F. (1985) Comparison of estimated item parameters of Shiba's word/phrase comprehension tests obtained by LOGIST 5 and by the tetrachoric method (Technical Report ONR-84-2). Knoxville, TN: University of Tennessee, Department of Psychology. December, 1984.

Samejima, F. (1985) Results of item-parameter estimation using LOGIST 5 on simulation data (Technical Report ONR-84-3). Knoxville, TN: University of Tennessee, Department of Psychology. December, 1984.

FORMULA-SCORE THEORY
NR 150-518
University of Illinois/Levine & Linn

Scientific Objectives: This work is more fully developing the Formula-score Theory (FST) approach to modelling performance on psychological tests. Within that formula-score framework it is developing techniques for gauging whether two psychological tests measure the same capabilities, for analyzing the relative contributions of well-defined capabilities to test performance, for describing the shapes of item-response functions, and for detecting changes in those item-response functions. In addition this work is exploring fundamental issues on equating multidimensional adaptive and conventional tests, on maximal curves for gauging the limits of appropriateness measurement procedures, and on the measurement of item bias in subpopulations.

Approach: Through a combination of theoretical and empirical studies the investigators are (a) refining procedures for obtaining and evaluating the quality of a canonical representation of ability distributions, (b) formulating procedures for measuring the equivalence of two capability distributions or two item-response functions, and (c) developing techniques for discovering the shapes of multidimensional item-response surfaces. In addition empirical studies will gauge the seriousness of drift in an equating between a multidimensional conventional and adaptive test as a result of successive replacement of items in the adaptive pool.

Progress: Major completed applications of FST include: (a) determining the shapes of item-response functions for a conventional unidimensional test, (b) providing a polychotomous model and accurately estimated response functions for the wrong responses and for omissions on a unidimensional test, (c) efficiently estimating unidimensional ability densities from small samples without assuming a parametric form, (d) increasing the reliability of scores on a conventional test by providing an ability estimator with the same conditional expected value and smaller conditional variance than number-right for examinees at every ability level. In addition progress has been made in developing a theoretical framework for (a) gauging the extent to which two tests measure the same thing, (b) discovering how two abilities interact to jointly determine performance on an item, and (c) estimating a two-dimensional ability distribution without the usual strong shape constraints.

Potential Applications: The availability of Formula-score Theory (FST) promises to provide the theoretical foundations for improvements in Navy and Marine Corps measurement activities of all types. Formula-score theory represents the functions needed to analyze a test as a linear combination of a small number of functions intrinsic to the test. The representation's simplicity encourages novel solutions to standard problems. For example, instead of transforming conventional scores on a new test to make them comparable to scores on an old test, FST shows how to compute a new score directly from the new test answer patterns. FST's linearity expedites reformulation of hard measurement problems (e.g., ability distribution estimation) as standard mathematical problems (maximize a convex function), and facilitates analysis of unidimensional tests and complex test batteries.

Reports:

Drasgow, F. & Levine, M. V. (1985). *Optimal detection of inappropriate test scores* (Tech. Rep. 85-1). Champaign, IL: University of Illinois, Model-based Measurement Laboratory.

Levine, M. V. & Drasgow, F. (1984). *Performance envelopes and optimaal appropriateness measurement* (Technical Report 84-5). Champaign, IL: University of Illinois, Model-based Measurement Laboratory.

Archival Publications:

Drasgow, F., Levine, M. V., & Williams, E. A. (1985). Appropriateness measurement with polychotomous item response models and standardized indices. *British Journal of Mathematical and Statistical Psychology*, *38*, 67-86.

DIMENSIONAL MISSPECIFICATION AND APPLICATIONS OF ITEM-RESPONSE THEORY
NR 150-542
University of Iowa/Wang

Scientific Objectives: In the absence of sound theoretical foundations for multidimensional item-response theory, there has been considerable confusion in the literature. Some researchers have equated psychometric dimensions with conceptual dimensions, arguing that a test problem which requires more than one ability (e.g., reading and arithmetic ability) necessarily requires a multidimensional model. Others have called upon the notion of a "complete latent space" to argue that a test model is inappropriately dimensioned if items appear to be conditionally dependent. Still others have called on the more widely understood, yet inappropriate, factor analytic conceptualization for their theorizing. This work will contribute to improving that situation by providing a theoretical framework for addressing dimensionality issues within a broad class of models.

Approach: A mathematical framework for representing the multidimensional situation for a broad class of item-response-theory models is being developed and will be used to anticipate the implications of multidimensionality for model calibration, for adaptive testing, for test bias, and for test equating. In addition, improvements to multidimensional modeling and adaptive technqiues are being explored.

Progress: An analytical framework based on the linearity of the item logic scores for the usual compensatory logistic item response model was defined. Within that framework algebraic relationships between unidimensional estimates and true multidimensional parameters were derived. Analytical results were demonstrated with simulated data. Finally, an index of the dimensionality of the latent space was suggested.

Potential Applications: Unidimensional models are currently the only practical vehicles for item-response-theory-based test development, administration, and scoring applications. Yet most useful item pools are multidimensional. Among other things this work will provide the theoretical wherewithal for addressing issues such as robustness and bias in specific applications.

PSYCHOLOGICAL TEST DIMENSIONALITY AND BIAS
NR 150-533
University of Illinois/Humphreys, Stout & Tucker

Scientific Objectives: The standard method of testing the dimensionality of binary items sets is to compute tetrachoric correlations, obtain the principal components, and inspect the latent roots. Unfortunately, tetrachorics have undesirable properties which limit their usefulness in practice: the matrix of tetrachorics is often non-Gramian and the sampling errors of the tetrachorics vary widely as a function of the difficulty levels of the items correlated. The objective of this work is to develop and compare improved methods for assessing dimensionality of binary tests.

Approach: The basic approach involves theoretical development of the various methods, analytic and Monte Carlo techniques for examining their statistical and numerical properties, and empirical studies to check results.

Progress: (1) A high-fidelity simulation model has been constructed which replicates the essential characteristics of typical cognitive data sets; (2) Empirical studies compared several indices based upon eigenvalue differences, patterns of factor loadings, and measures of conditional independence. While none of the indices was wholly satisfactory, the index based upon conditional independence faired better especially with large sample sizes, large numbers of items, narrow ranges of item difficulty, and when distinguishing between 1- and 2-dimensional data; (3) A Monte Carlo study of Stout's test of unidimensionality has been completed. Results indicate that when combined with Stout's bias correction procedure, the test performs well for the test lengths and population sizes typically encountered in practice; (4) A mathematically rigorous notion of the "essential" dimensionality of a test has been developed, which captures the reality that performance on test items is multiply determined. A theoretical analysis indicates that Stout' s test has good power against "non-essentially" unidimensional alternatives; and (5) A rigorous notion of test bias has been framed in terms of the essential dimensionality of the test in certain subpopulations. Based upon this notion a statistical test of test bias has been formulated and is currently being evaluated.

Potential Applications: In adaptive testing different examinees answer different sets of test items. In such circumstances, arbitrarily selected sets of items must measure the same essential dimension. Methods under development in this project will help test constructors insure that this is the case.

FULL-INFORMATION FACTOR ANALYSIS OF THE CAT-ASVAB ITEM POOL

NR 150-541
National Opinion Research Center/Bock

Scientific Objectives: This work involves (a) improvements to the Bock-Aitkin algorithm for full-information factor analysis, (b) application of the procedures to assess the dimensional structure of the item pools developed for operational use of the computerized adaptive version of the Armed Services Vocational Aptitude Battery (CAT-ASVAB), and (c) the development of practical strategies for dealing with multidimensionality in CAT-ASVAB subtests.

Approach: Empirical studies of the dimensional structure of the CAT-ASVAB item pools are being conducted for explanations of obtained multidimensionality. Empirical studies are examining the performance of several techniques for the modeling of guessing on psychological test items. Techniques are also being explored for adaptively administering multidimensional subtests.

Progress: The first phase of this effort focused on extending the full-information factor analysis procedures to include estimation of lower asymptote parameters and new and faster numerical methods for evaluating marginal likelihoods. To avoid the problem of fitting a "guessing factor", investigators tested a one-dimensional model with a non-zero lower asymptote parameter before increasing model dimensionality. After the number of dimensions was determined, improvements to the estimate of the lower-asymptote parameter were sought. To speed up calculations, investigators explored the use of "adaptive" quadrature: the likelihoods were evaluated only at points which have appreciable posterior probability. These points were identified from each examinee' s estimated factor scores and their standard error of measurement.

Potential Applications: Several factors underscore the importance of this work to the Services: First, adaptive testing is not appropriate with seriously multidimensional item pools. Second, the Bock-Aitkin algorithm is the only well developed technique for assessing multidimensionality in an item-response-theory sense which assigns items to dimensions. Third, applications of the algorithm to the Profile of American Youth ASVAB data set suggested serious multidimensionality in certain subtests. Fourth, there is a possibility that some of these additional dimensions may not show up in the somewhat narrower military applicant population. Fifth, there is a possibility that some of the additional dimensions are artifacts of the inadequacies of the Bock-Aitkin algorithm for the modelling of guessing. Finally, inasmuch as substantial further subdivision of ASVAB into more homogeneous classes is impractical, alternate adaptive strategies are required.

Funding: Air Force

MODELLING CONDITIONAL DEPENDENCIES AMONG PSYCHOLOGICAL TEST ITEMS
NR 150-538
University of Illinois-Chicago/Gibbons

Scientific Objectives: An assumption of conditional independence has been commonplace in theoretical and practical work in item-response theory. The assumption states that item scores are related to each other only through their relationship with examinee ability. This means that item scores are statistically independent for examinees with the same ability. This work is developing techniques (a) for gauging the extent of conditional dependencies among test items, (b) for obtaining efficient ability estimates in spite of minor dependencies, and (c) for explicitly modelling dependencies in response data.

Approach: Initial work is focused on theoretical and numerical development of the techniques. Subsequently, techniques will be validated with Monte Carlo simulation and with actual data sets.

Progress: This work began late in 1985, and no Status Reports have yet been issued.

Potential Applications: (a) Substantial evidence suggests that conditional dependencies exist in many Navy and Marine Corps testing applications. These include, for example, multiple questions about a single paragraph in paragraph-comprehension test item, about a single schematic in items on a electronics test, or about a single problem situation in a problem-solving task; (b) Extant technology either for identifying or for dealing with conditional dependencies when they exist is wholly inadequate,; (c) Ignoring conditional dependencies when they exist at best decreases the efficiency of ability estimation and at worst leads to the wrong conclusions.

ON-LINE CALIBRATION FOR THE ADAPTIVE ASVAB

NR 150-520
Educational Testing Service/Lord, Stocking, & Holland
University of Chicago/Bock
University of Illinois/Levine
University of Tennessee/Samejima

Scientific Objectives: The calibration of replacement test items for the adaptive Armed Services Vocational Aptitude Battery (ASVAB) requires techniques for accurately estimating item-response functions from the sparse data sets available during administration. It is the objective of this work unit to develop and evaluate techniques for that purpose.

Approach: Four methods of on-line item calibration are being formulated and compared. These methods are extensions of the principal off-line calibration methods and include techniques based upon marginal maximum-likelihood (see NR 150-541 and 475-018), joint maximum-likelihood, formula-score theory (see NR 150-518), and Samejima' s non-parametric approach (see NR 150-467). The results of the application of each technique will be fitted three-parameter logistic item-response functions. Performance of the methods will be compared using common criteria and simulated ASVAB data sets.

Progress: Substantial progress has been made in extending and improving the four calibration techniques. Further improvements and testing with Monte Carlo studies are in progress. In addition, rudimentary techniques for modelling trends in item parameters have been developed and tried out on real data sets. Analyses suggest that changes in item difficulty do occur, but are slow and regular. Improvements to the procedure and techniques for appropriate compensatory adjustments are under study.

Potential Applications: On-line calibration techniques are essential for the anticipated adaptive ASVAB. Initially, these techniques will be needed to check calibrations obtained from studies in which items were administered under experimental instructions and in paper-and-pencil format. Subsequently, these techniques will be used to calibrate replacement items and to maintain scale integrity.

Funding: ONR, AFHRL, MEPCOM, NPEDC, OASD (M6RA)

Archival Publications:

Lord, F. M. (1984). Standard error of measurement at different ability levels. Journal of Educational Measurement, 21, 239-243.

Lord, F. M. (1985). Estimating the imputed social cost of errors of measurement. Psychometrika, 50, 57-68

Lord, F. M., b Wingersky, M. S. (1984). Comparison of IRT-true-score and equipercentile-observed-score "equatings". Applied Psychological Measurement, 8, 453-461.

Samejima, F. (1984). Review of Doignon, J.P. and Ducamp, A., On the realizable biorders and the biorder dimension of a relation. *Journal of Mathematical Psychology*, *28*, 73-109.

Wingersky, M. S., & Lord, F. M. (1984). An investigation of methods for reducing sampling error in certain IRT procedures. *Applied Psycholoical Measurement*, *8*, 347-364.

THE INTERPRETATION AND APPLICATION OF MULTIDIMENSIONAL ITEM-RESPONSE THEORY MODELS

NR 150-531
American College Testing Program/Reckase & Carlson

Scientific Objectives: This work is developing useable multidimensional item-response theory (MIRT) for training applications. Various lines of work are exploring (1) the adequacy of compensatory models for characterizing typical training performance; (2) techniques for increasing the accuracy and efficiency of item-response-function-estimation algorithms (especially in small samples); (3) extensions of the unidimensional notions of item difficulty, discrimination, and information to a general class of MIRT models; (4) the implications of adaptive item selection for the complexity of the content dimensions being measured; (5) the effectiveness of appropriateness indices for detecting items whose characteristics have changed since the response models were originally calibrated; and (6) the nature of and effective methods for dealing with the trade-off between test efficiency and test security in applications.

Approach: The shapes of theoretically and empirically determined item-response functions are compared to investigate the adequacy of the more tractable compensatory models. Bayesian procedures are explored to increase the efficiency of multidimensional-item-response-function estimation in small samples. The theoretical relationship between multidimensional difficulty and a local notion of item information is studied. Reckase' s previous work on the relationship between target and obtained content of tests which have been optimized via item-response theory is extended (see NR 150-474). Finally, results are validated in the Marine Corps Communications Electronics School at Twenty-nine Palms, CA.

Progress: A definition of the difficulty of an item which measures more than one dimension has been formulated. This definition represents an item's difficulty as an n-dimensional vector, where n is the number of skills being tapped. The unidimensional notion of an item information function was extended to the multidimensional case. This extension indexes the extent to which performance on the item differentiates among examinees with particular combinations of skills. A detailed study of how multidimensional difficulty and discrimination can be used to form item sets which operate as if they were unidimensional has been conducted. The hypothesis was that a set of items which have their highest discrimination in roughly the same direction will operate as if it were unidimensional. Analyses of data from a mathematics-usage test generally supported this hypothesis, although some small item sets which were fairly difficult were problematic.

Potential Applications: This work addresses several important issues in multidimensional item-response theory: model specification, model estimation, and test construction. Progress on each of these issues is important if multidimensional item-response theory is to be made practical, for example, with large item pools or with small samples.

Archival Publications:

Reckase, M. D. (1984). Review of "Applications of Item-response Theory" by R. K. Hambleton (Ed.). Educational Measurement: Issues and Practice, 3, 26-27.

Reckase, M. D. (1984). Scaling techniques. In G. Goldstein and M. Herson (Eds.), Handbook of psychological assessment. New York: Pergamon Press.

Reckase, M. D., (1985) The difficulty of test items that measure more than one ability. Applied Psychological Measurement, 9, 401-412.

Reckase, M. D. & McKinley, R. L. (1985). Some latent-trait theory in a multidimensional latent space. In D. J. Weiss (Ed.), Proceedings of the 1982 item-response theory and computerized adaptive testing conference. Minneapolis, MN: University of Minnesota, Department of Psychology.

A DISCRETE LATENT STATE APPROACH TO DIAGNOSTIC TESTING
NR 150-466
Portland State University/Paulson

Scientific Objectives: The purpose is to improve the measurement foundations of tests for mastery of specific concepts. The general principle guiding the effort is that the characterization of knowledge states should be derived from psychological theory and that the measurement model should relate performance to those knowledge states.

Approach: Latent class models are explored which represent examinees as being in one of a small number of states. Estimation procedures are developed to estimate model parameters. Goodness-of-fit statistics are developed to assess the likelihood of the model given the data. The performance of the procedures are examined using data on signed-number arithmetic.

Progress: (1) Estimation procedures for model parameters based on the EM algorithm were developed. These procedures substantially increase the number of items which can be handled simultaneously by the latent-class models. (2) Indices of model fit based on a likelihood ratio statistic have been developed. (3) Empirical studies aimed at modelling signed-number-arithmetic performance were completed. Results indicated that while complex models are needed to diagnose many of the student misconceptions, simpler models do surprisingly well. (4) A test for dimensionality based upon so-called "monotonic homogeneity" considerations was suggested.

Potential Applications: In many Navy and Marine Corps training contexts, instructors have explicit notions of the typical misconceptions which occur at various points in the instructional sequence. In those circumstances these models provide the theoretical wherewithal to relate performance data to specific misconceptions.

Report:

Paulson, J. (1985). Latent class representations of systematic patterns in test responses (Technical Report 85-1). Portland, OR: Portland State University, Department of Psychology.

TECHNIQUES FOR DLAGNOSING ERRORS ON PROBLEM SOLVING TASKS
NR 150-495
University of Illinois/Tatsuoka, Tatsuoka, & Eddins

Scientific Objectives: To develop a stochastic model that is capable of diagnosing and classifying cognitive errors in well-defined procedural domains to apply the model to detect weaknesses in instructional materials, to optimize remedial procedures, and to evaluate psychological models.

Approach: A theoretical framework for diagnosing errors in procedural skills is refined by improving the parameter estimation and pattern classification technologies and by incorporating measures of error consistency and response time. Work aimed at modelling transitions of error types as a trainee progresses through a course of instruction explores the use of Markov chains. A general method of item construction for tests of procedural knowledge is sought. Finally, the generalizability of results is checked in a Navy Basic Electricity and Electronics school.

Progress: Accomplishments include: (1) "Rule Space", which is the Cartesian product of an examinee's trait standing and a measure of the consistency of h,is/her response pattern with the model, was refined and tried out in a variety of domains. Results confirmed its ability to diagnose well-defined procedural errors in signed-number arithmetic, arithmetic with fractions, English grammar, and algebra. (2) Previous studies indicated a strong relationship between the consistency with which trainees apply their rules and their level of expertise in a procedural domain. To gauge consistency, properties of the determinant of the covariance matrix over parallel subtests were examined. Experimental studies comparing the consistency of groups taught by different methods suggested that the method with more consistent rule application had a higher retention rate one year later. (3) Techniques for gauging the seriousness of incorrect rules using the norm-conformity index have been formulated. (4) A new adaptive procedure has been designed. Essentially it is a multivariate, minimum-variance optimization procedure and yields substantial savings in the number of items needed for a diagnosis.

Potential Applications: This project has four broad areas of application. First, it is exploring quantitative methods for assisting the instructional designer in studying the structure of a domain to be learned, in identifying weaknesses in existing instructional materials, and in selecting test questions to make efficient use of testing time. Second, it is exploring a variety of techniques for specifying, estimating, and evaluating performance models which will enable more specific diagnoses and which will serve as the basis for the prescription of remedial materials. Third, it is exploring quantitative techniques for studying the seriousness of particular misconceptions as a basis for deciding whether to remediate them before moving on to new material. Finally, it is exploring the problem of communicating often abstract diagnoses to instructors and to trainees in ways that will be useful to them.

Reports:

Tatsuoka, K. K. (1985). Diagnosing cognitive errors: Statistical pattern classification and recognition approach (Research Report 85-1-ONR). Urbana, IL: University of Illinois, CERL.

Tatsuoka, K. K., & Tatsuoka, M. M. (1985). Bug distribution and pattern classfication (Research Report 85-3-ONR). Urbana, IL: University of Illinois, CERL.

Tatsuoka, K. K., & Yamamoto, K. (1985). Application of component scoring to a complicated cognitive domain (Research Report 85-2-ONR). Urbana, IL: University of Illinois, CERL.

Archival Publications:

Birenbaum, M., & Shaw, D. (1985). Task specification chart: A key to a better understanding of test results. Journal of Educational Measurement, 22,

Morimoto, Y., & Tatsuoka, K. K. (1984). Analysis of misconceptions in fraction problems: Interactive diagnostic system on the PLATO system. In The Proceedings of ICMI-JSME Regional Conference on Mathematics Education, Tokyo.

Tatsuoka, K. K., (1985). A probabilistic model for diagnosing misconceptions in the pattern classification approach. Journal of Educational Statistics, 10, 55-73.

Tatsuoka, K. K. (1985). A latent trait model for interpreting misconceptions in procedural domains. In D. J. Weiss (Ed.), Proceedings of the 1982 Item Response Theory and Computerized Adaptive Testing Conference Minneapolis, MN: University of Minnesota.

Tatsuoka, K. K. (1985). Review of Test of English as a Foreign Lanaguage. Lincoln, NE: The University of Nebraska, The Buros Institute of Mental Measurements.

Tatsuoka, K. K. (1985). Review of the Test of Spoken English. Lincoln, NE: The University of Nebraska, The Buros Institute of Mental Measurements.

Tatsuoka, K. K., & Eddins, J. M. (1985). Rule space. In S. Kotz & N. L. Johnson (Eds.), Encyclopedia of Statistical Sciences, Vol 2. New York: Wiley.

WORKSHOP AND CONFERENCE ON DIAGNOSTIC MONITORING OF KNOWLEDGE AND SKILL ACQUISITION

NR 667-553
Educational Testing Service/Frederiksen

Scientific Objectives: To foster new thinking and ultimately new approaches for representing and diagnosing trainee knowledge and skill as it evolves in the course of instruction.

Approach: A group of 18 innovative researchers from the fields of artificial intelligence, cognitive psychology, and psychometrics will meet to discuss the difficult theoretical and practical problems of automated cognitive diagnosis. An initial meeting was held to define the focus of the participants' efforts, to define areas of common interest, and to establish collaborative relationships among some of the researchers. At a second formal conference, participants will present the results of their efforts. A proceedings will be published in book form.

Progress: This work began late in FY 85, and no Status Reports have yet been issued.

Potential Applications: Experimental, mathematical, and computational investigations of complex knowledge structures and their relation to behavior are central to the Navy and Marine Corps personnel and training research interests. This effort will result in improvements in intelligent training systems and AI-based classroom aids.

BAYESIAN TECHNIQUES FOR ITEM-RESPONSE THEORY

NR 150-535
University of Missouri-Columbia/Tsutakawa

Scientific Objectives: In item-response theory (IRT) an examinee' s item responses are linked to an ability scale through item-response functions (IRF). In the typical IRT application, these IRFs are partially known through a calibration based on examinees who have previously taken the same test. The typical application proceeds as if these IRFs were well-estimated; in effect this assumed that the calibrations are exact. In previous work Tsutakawa developed techniques for representing uncertainty about the calibrations of these IRFs. In this project that representation is checked and used to more accurately represent what is known about an examinee's ability. Subsequently, this improved representation of an examinee' s ability will provide better estimates of IRFs for new, uncalibrated items.

Approach: This work is employing a combination of theoretical development of the techniques, Monte Carlo simulation to check the performance of the techniques under controlled conditions, and validation with actual response data.

Progress: Initial research focused on efficient procedures for estimating the marginal posterior distributions of individual ability parameters. Approximations by Leonard, bv Tierney and Kadane, and by Lindley were studied, but in the general case were not practical for routine use. Research examined a new Bayesian approach based upon normal approximation of the posterior item-parameter distribution and its theoretical properties are under study.

Potential Applications: The use of model-based procedures for test development and scoring in Navy and Marine Corps training schools has been hampered by statistical estimation problems. Standard procedures for estimating IRFs require large item pools and substantial samples of examinees--requirements which are virtually unattainable in the typical military training context. When standard procedures are used with small item pools and with small numbers of examinees, results can be misleading. This effort will improve that situation.

NON-PARAMETRIC ESTIMATION OF THE LATENT-TRAIT DENSITY
NR 150-537
University of Missouri/Speckman

Sciuentific Obiective: This research is exploring two new approaches for characterizing ability densities underlying performance on psychological tests. Each approach represents the ability density as an exponential spline in which the exponent is in a finite-dimensional space of linear spline functions. One approach is seeking to maximize the marginal likelihood over than class. A second approach is seeking to maximize a penalized marginal likelihood. Each approach is expected to provide smooth non-negative density estimates without further constraints.

Approach: Initial work is focused on theoretical and numerical development of the techniques and on evaluation via Monte Carlo simulation. Subsequent work will evaluate performance using actual response data via suitable cross-validated designs. Ultimately, these techniques will be folded into marginal-maximum-likelihood approaches for estimating item-response functions (see NR 150-535)

Progress: This work began late in FY85, and no Status Reports have yet been issued.

Potential Applications: The accurate characterization of unobservable ability densities is a central problem in psychological measurement. It is a central part of the assessment of model appropriateness (NR 150-518), of the non-parametric characterization of item-response functions (NR 150-467 & NR 150-518), and of efficient estimation of individual abilities, This work is expected to substantially increase the accuracy of ability density estimates and thereby increase the fidelity of other measurement results.

THEORY OF ROBUSTNESS FOR ITEM-RESPONSE THEORY
NR 150-522
Advanced Statistical Technologies Corporation/Jones

Scientific Objective: This work is seeking a theoretical framework and tractable procedures within that framework for gauging the robustness of estimators of item-response functions and of examinee ability. In addition a theory of optimal estimation is being formulated and, where feasible, optimal estimators derived.

Approach: (1) Influence functions appropriate for item-response theory are explored; (2) Formulas for the efficiency of several robust estimators are derived and empirically studied; and (3) Several item-response-function models are studied and rigorous characterizations of neighborhoods of these - models are derived as a basis for examining optimality.

Progress: The sensitivity of maximum-likelihood procedures to unusual data and to model misspecification has been characterized. Work on the sensitivity of maximum-likelihood procedures to unusual data has extended Pregibons' methods to item-response theory; to accomplish this, the Newton-Raphson algorithm (the standard numerical technique for obtaining maximum-likelihood estimates) was reformulated in terms of non-linear least squares. This reformulation permitted the derivation of closed formulas for the effects of deleting one or two observations from a data set on estimates, confidence intervals, and goodness-of-fit statistics. Work aimed at gauging the sensitivity of maximum-likelihood procedures to model misspecification obtained a general parametric class of item-response functions within which one can characterize neighborhoods of the standard 1-, 2-, and 3-parameter-logistic models. Examination of the breakdown points of the standard models indicated that at low abilities the bias of the maximum-likelihood ability estimator for the 1- and 2-parameter models was extremely sensitive to model misspecification.

Potential Applications: In practical applications of item-response theory it is guaranteed that the assumed model and the true model will differ. Consequently, understanding the sensitivity of standard estimation techniques to such differences is essential. In addition the maximum-likelihood diagnostics under development here identify items and people whose behavior seems to depart markedly from model predictions. These can be used to adjust models, to exclude aberrant items, and to identify examinees who may have exceptional knowledge.

HIERARCHICAL-BAYES ESTIMATION OF ITEM-RESPONSE MODELS
NR 150-539
Educational Testing Service/Mislevy

Scientific Objectives: Techniques for estimating item-response functions perform poorly when sample sizes or test lengths are small. This work will improve that situation by extending hierarchical Bayesian techniques to this context. Essentially, techniques are developed which take advantage of collateral information about persons (e.g., years of schooling) and items (e.g., cognitive processing requirements) to improve estimation within the item-response-theory framework.

Approach: The hierarchical-Bayesian approach is employed to estimate the relationships between model parameters (i.e., parameters describing attributes of individual items and examinees) and collateral information. Bayesian and empirical-Bayesian estimation procedures provide modal estimates of item and structural parameters via a variant of the EM algorithm, Results will be evaluated on data from the Armed Services Vocational Aptitude Battery (ASVAB) and from the National Assessment of Educational Progress (NAEP) program.

Progress: A theory for incorporating collateral information about examinees through a generalized linear model was developed. The case of categorical collateral variables (e.g., high school graduation and gender) was completed. Empirical results with ASVAB data indicated that use of these procedures increased the precision of item parameter estimates substantially. A more general model incorporating collateral information about both items and examinees is under development.

Potential Applications: On-line calibration of new test items is currently hampered by the sparsity of data at the level of individual examinees--in adaptive administration of ASVAB only 15 responses to previously calibrated items are planned. Judicious use of auxiliary information about examinees and items could increase the precision of item parameter estimation and reduce its bias by amounts comparable to increasing the test length by 20%, without requiring additional testing time.

EQUATING COMPUTER-BASED-ADAPTIVE AND PAPER-AND-PENCIL ASVAB
NR 150-534
Johns Hopkins University/Green

Scientific Objectives: This work is developing techniques for equating computer-based-adaptive and paper-and-pencil versions of the Armed Services Vocational Aptitude Battery. This includes the development of techniques for verifying and re-estimating item-response functions with adaptive data sets and for equating multi-faceted paper-and-pencil and adaptive tests,

Approach: (1) Theoretical expressions for the attenuation in item parameter estimates as a function of ability distribution and sample size are developed. (2) Issues concerning the design of the recalibration/equating data collection study are examined via Monte Carlo simulation. (3) Techniques for detecting mode-of-administration and mode-by-item interactions are developed and validated with simulation data. (4) A variety of techniques for equating adaptive scores to number-correct scores on the Auto-Shop subtest are compared.

Progress: A detailed study of the effects of computer presentation and of alternate scoring methods for ASVAB speeded subtests has been completed. Results indicated that a scoring method gauging the number of correct responses per minute was superior to the traditional method of counting the number of correct answers in a fixed time period. The reliabilities of scores on the computer-presented versions were at least as high as that of the paper-and-pencil versions. Examinees responded faster on the computer-presented versions than on their paper-and-pencil counterparts. Correlations between computer-based and paper-and-pencil versions of the numerical-operations subtest were substantial.

In other work investigators examined the viability of a number of options for DoD's adaptive ASVAB: (a) Simulations of data collection strategies showed that data from 5 "seeded" items will not be sufficient for item re-calibration; data from adaptively-administered items may be required. (b) Simulations of the impact of fixing lower asymptote parameters at incorrect values showed that estimates of other parameters compensate for the incorrect lower asymptotes. The net result is that ability estimates are affected very little. (c) Simulations of the impact of reduced pool size confirmed that the information loss is modest. (d) Simulations are currently underway to examine the effects of exposure-control strategies on the performance and quality of adaptive tests.

Potential Applications: To get off the ground with a computer-based adaptive ASVAB, the Services need (a) large banks of test questions on which item response functions have been calibrated and (b) mathematical functions which map scores on the computer-based adaptive test onto scores on the equivalent paper-and-pencil version of the test. Since initial calibrations were necessarily obtained from data gathered in paper-and-pencil format and examinees were told that the test was experimental, the generalizability of the item-response functions to the operational environment is uncertain. Furthermore, in the ASVAB environment decisions about about a candidate's suitability for a particular Service School must be made on the spot. Therefore, techniques for bootstrapping are needed. At the least this work will make clear how difficult accuracy really is. It should also make clear the extent to which we can have confidence in item-response functions calibrated under experimental instructions and in paper-and-pencil format. At best this work will provide techniques for equating multi-faceted tests by adjusting calibrations.

Funding: NPEDC

BAYESIAN INFERENCE IN FACTOR ANALYSIS
NR 150-536
Sloan-Kettering Cancer Research Center/Wong

Scientific Objectives: This effort extends previous work on Bayesian approaches to factor analysis. A framework for characterizing the moments of the marginal posterior distributions of the factor loadings, factor scores, and uniqueness variances is developed; expressions of estimation errors are derived and compared with those obtained under maximum-likelihood and Bayes-joint-modal approaches; and the sensitivity of the marginal moments to variations in the prior distributions is examined. In addition, these marginal procedures are extended to the study of oblique factor models, of models with *a priori* zero factor loadings, and simultaneous factor models.

Approach: This work employs a combination of theoretical development of the techniques and Monte Carlo simulation to check the performance of the techniques under controlled conditions. A central element of this research involves approximating the marginal moments of the posterior distributions of factor loadings, factor scores, and uniqueness variances. Techniques based upon an extension of the so-called Tiao-Zellner expansion and refinements of the EM algorithm are being explored.

Progress: This work unit began late in FY85, and no Status Reports have yet been received.

Potential Applications: Technical difficulties with maximum-likelihood and previous Bayesian approaches to factor analysis of ability data include: (a) flat likelihood surfaces in a neighborhood of the global maximum; (b) multiple local maxima; (c) asymptotic sampling theory which is inadequate even for moderate samples, and small-sample theory which is nonexistent; (d) dogmatic treatment of loadings judged on a priori evidence to be small; (e) underestimation of uniqueness variances; and (f) lack of analyses gauging the sensitivity of these procedures to perturbations in the prior distributions. This research will ameliorate many of those problems.

BAYESIAN MODELS FOR PERSONNEL SELECTION AND CLASSIFICATION

NR 150-521
University of Iowa/Novick

Scientific Objectives: In previous work Novick developed sophisticated methods for fitting regressions simultaneously in multiple groups, for drawing inferences from non-experimental data sets, and for setting cut scores for psychological tests in decision-making environments. The validity and usefulness of those techniques is examined further by applying them to prototypical military data sets.

Approach: The relationships between Armed Services Vocational Aptitude Battery (ASVAB) scores and biographical and demographic variables on the one hand and military performance variables on the other are being examined using Bayesian simultaneous regression techniques within schools/locations/Services and occupational groupings. Formal Bayesian utility assessment and maximization techniques are being employed to determine optimal cut scores for military selection and for assignment to selected schools and to selected military occupations.

Progress: Completed research provided evidence for differential prediction by gender, training course, an educational background, but not by race. One study showed that the use of educational background as a moderator substantially reduced differential prediction on ASVAB variables. In another set of studies the use of simultaneous estimation of regressions showed that courses within broad categories, such as mechanical or clerical, can often be clustered to provide subgroups in which common prediction is warranted. Several methodological developments were obtained. An improved method of Bayesian estimation in two-by-two contingency tables and an improved Bayesian regression algorithm were developed.

Potential Applications: With present selection technology, prediction functions for low-frequency schools/occupations or for low-frequency population subgroups are poorly estimated and cut scores are established without resort to utility considerations. This work will improve that situation.

Funding: OASD (M&RA) and MEPCOM

Reports:

Dunbar, S. B., Mayekawa, S., & Novick, M. R. (1985). Simultaneous estimation of regression functions for Marine Corps technical training specialties (Technical Report 85-1). Iowa City, LA: University of Iowa, Center for Measurement. (AD 150477)

Dunbar, S. B. & Novick, M. R. (1985). On predicting success in training for males and females: Marine Corps clerical specialties and ASVAB forms 6 and 7 (Technical Report 85-2). Iowa City, IA: University of Iowa, Lindquist Center for Measurement. (AD 152080)

Leonard, T., & Novick, M. R. (1985). Bayesian inference and diagnostics for the three parameter logistic model (Technical Report 85-5). Iowa City, IA: University of Iowa Lindquist Center for Measurement.

Leonard, T., & Novick, M. R. (1985). Bayesian full rank marginalization for two-way contingency tables (Technical Report 85-4). Iowa City, IA: University of Iowa Lindquist Center for Measurement. (AD 153841)

Mayekawa, S. (1985). Bayesian factor analysis (Technical Report 85-3). Iowa City, IA: University of Iowa Lindquist Center for Measurement. (AD 154184)

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR

MODELS FOR MULTIDIMENSIONAL TESTS AND FOR HIERARCHICALLY-STRUCTURED TRAINING MATERIALS
NR 150-474
American College Testing Programs/Reckase

Scientific Objectives: The objectives were to develop and to evaluate probabilistic models: (a) for the performance of individuals on test items which require proficiency on more than one skill and (b) for the relationship between performance on two units of instruction when one contains material which is prerequisite to the other.

Approach: The approach taken was to logically evaluate the characteristics of potential models, to develop estimation procedures for model parameters, and to evaluate the models on their ability to describe real test data. These steps were performed separately for a wide class of models.

Results and Conclusiions: Work on multidimensional models extensively studied a multidimensional extension of the two-parameter-logistic model. Estimation procedures were developed and the results were validated using simulated and real test data. A conceptual framework was outlined for the interpretation of model parameters and multidimensional extensions of the unidimensional notions of item difficulty, discrimination, and information were obtained, Remaining deficiencies that were noted include the following: (a) estimation programs required an excessive amount of computer time when more than two dimensions were specified, and (b) Procedures were needed to assess the fit of the model.

In other work a model of the relationship between performance on instructional modules which are hierarchically arranged was developed and evaluated using simulated and real test data. One problem with the use of the model surfaced, however. To accurately estimate model parameters, in a calibration study trainees must be advanced to higher-level units even when they have performed poorly on lower-level units. Because this is viewed as poor educational practice, needed data often cannot be obtained.

Reports:

Reckase, M. D. (1985). Models for multidimensional tests and hierarchically structured training materials (Final Report ONR-85-1). Iowa City, IA: The American College Testing Program.

THE USE OF TAILORED TESTING IN INSTRUCTIONAL PROGRAMS
NR 150-499
American College Testing Programs/Reckase

Scientific Objective: This project developed, implemented and studied a computer-based testing system for the Navy's Radar Technicians Course at Great Lakes Navy Training Center. The objective was to produce a more efficient testing procedure and to improve the quality of measurement.

Approach: The system was a multi-level, microprocessor-based computer network with each testing station capable of operating as a stand-alone test administration system. The system was used to administer tests in a sequential, fixed-length format. Although software was also developed for adaptive administration, the system was never used for adaptive testing because of repeated hardware failures.

Results and Conclusions: In addition to system development and implementation work, research studies were conducted on model selection study, mode-effects, and an attitude survey. The model-selection study compared ability estimates obtained using the Rasch model with ability estimates obtained using the three-parameter-logistic (3PL) model. Results indicated that adaptive ability estimates from the Rasch and 3PL models are highly correlated; there were no systematic differences in measurement quality between them. Consequently, since the Rasch model procedure is substantially less expensive, it was recommended for sparse data environments like those for adaptive testing. The mode-effects study compared performance on paper-and-pencil and computer-based versions of the 86 items used in the Navy's Radar Technicians' Course. Analyses of estimated item difficulty parameters identified 26 items (or 30%) affected by mode of administration; 11 items were harder when administered by computer, and 15 were easier. Several hypotheses such as differences being related to the amount of verbal material in the item or item format differences were eliminated; however, no obvious explanations were identified.

Results of the attitude survey indicated that electronics-technician trainees had little difficulty with the computer-based system. Trainees reported difficulty in reading the screen, with eye fatigue, or in finding the proper keys on the keyboard. The only commonly voiced complaint concerned the lack of a procedure for reviewing previously-answered items.

Potential Applications: This project demonstrated that microcomputers could be effectively used to administer achievement tests in a Navy instructional environment. Second, it showed that the Rasch model may be adequate for adaptive testing in the typical data-sparse Navy and Marine Corps training environments. Third, it underscored the need for caution in adapting paper-and-pencil test items to computer format. Fourth, it suggested the need for procedures which can accommodate review and answer-changing in the course of adaptive tests.

MARGINAL-MAXIMUM-LIKELIHOOD ESTIMATION IN ITEM-RESPONSE THEORY
NR 475-018
National Opinion Research Center/Bock

Scientific Objectives: In this work, the usefulness of recent theoretical developments in marginal-maximum-likelihood methods for estimating item-response functions, for gauging the dimensionality of tests, for simultaneous multidimensional adaptive testing, and for estimating the trait distributions of selected subpopulations were explored in a military context.

Approach: Empirical studies employing Armed Services Vocational Aptitude Battery (ASVAB) data from the Profile of American Youth program were used. cross-validated. Estimated item-information functions were examined in light of item content and evidence for multidimensionality. Several methods for estimating subtest trait distributions were also examined and compared.

Results and Conclusions: (1) A four-phase Bayes constrained estimation procedure extended Bock's earlier work to the three-parameter-logistic situation. These procedures were successfully applied to the Profile of American Youth data set. (2) Analysis of the dimensionality issue suggested that the Auto-Shop subtest was two-dimensional. (3) A multiple-category model for incorporating information from wrong responses to multiple-choice items was developed and tried with the ASVAB data set.

Potential Applications: (a) The multiple category model makes possible the recovery of information available in wrong responses to multiple-choice test items and can thus increase the speed and accuracy of computerized adaptive testing. The model also provides so-called category operating characteristics. Those functions can be used by test designers to assess the effectiveness of distractors in multiple-choice test items; and (b) The full-information factor analysis developed in this work ought to replace traditional linear factor analysis. The full-information approach not only conforms more closely to the latent-trait non-linear notion of dimensionality, but also reduces the likelihood of obtaining spurious guessing factors.

Funding: ONR Manpower R&D Program.

Reports:

Bock, R. D., Gibbons, R., & Muraki, E (1985). Full-information item factor analysis (Technical Report 85-1). Chicago, IL: University of Chicago National Opinion Research Center.

Mislevy, R. J., & Bock, R. D. (1984). Item operating characteristics of the Armed Services Vocational Aptitude Battery (ASVAB), form 8A (Technical Report). Chicago, IL: University of Chicago National Opinion Research Center.

Thissen, D,. & Steinberg, L. (1984). A response model for multiple choice items (Technical Report). Chicago, IL: University of Chicago National Opinion Research Center.

Archival Publications:

& L

Mislevy, R. J. (1984). Estimating latent distributions. Psychometrika, 49, 359-381.

Thissen, D. b Steinberg, L. (1984). A response model for multiple choice items. Psychometrika, 49, 501-519.

ADAPTIVE ASSESSMENT OF SPATIAL ABILITIES
NR 154-531
Educational Testing Service/Bejar

Scientific Objectives: This research developed and evaluated latent-trait techniques for modelling individual differences in performance on spatial tasks.

Procedure: Investigators conducted a comprehensive review of the literature to select a set of spatial tasks for study. Appropriate latent-trait models and estimation procedures were developed. Performance data were collected and models calibrated. Finally, results were linked to explanations of individual differences obtained through other approaches.

Results and Conclusions: A three-dimensional spatial-rotation task and a hidden-figures task were selected for study and response data were collected on approximately 200 participants. Samejima's continuous response model (see NR

150-467) was modified to account for the fact that examinees cannot respond instantaneously and that some examinees may run out of time.

Data for the rotation task were collected from the 200 examinees each responding to 80 items. There were eight basic items presented at five angles in their "true" and "false" versions. Models were fit to the response-time data for the "same" and "different" responses separately. Analyses examined the relationship between the size of the difficulty parameter and certain item attributes. For the three-dimensional spatial-rotation tasks, results confirmed the well-established linear relationship between response time and rotation angle on the "same" items. Analyses provided no new insights into response-time differences on "different" items. Analyses of the hidden-figures task showed that an item-generation algorithm can be formulated to produce item "clones" with similar psychometric characteristics.

Potential Applications: It was anticipated that the application of these mathematically-sophisticated modelling techniques would filter out much of the "noise" in the response data and thereby increase measurement fidelity and our understanding of the nature of the individual differences on these tasks. Since many Navy and Marine Corps tasks engage spatial capabilities, it was anticipated that this increased understanding would suggest improvements in selection, task design, and training.

Reports:

Bejar, I. (1986). Adaptive assessment of spatial abilities (Final Report) Princeton, NJ: Educational Testing Service.

Bejar, I. (1986). The Psychometrics of mental rotation (Technical Report RR-86-19). Princeton, NJ: Educational Testing Service.

Bejar, I. (1986). Analysis and generation of hidden figure items: A cognitive approach to psychometric modelling (Technical Report RR-86-20) Princeton, NJ: Educational Testing Service.

Bejar, I. (1986). Adaptive assessment of spatial abilities (Final Report) Princeton, NJ: Educational Testing Service.

Archival Publications:

Bejar, I. (1985). Educational diagnostic assessment. Journal of Educational Measurement, 21, 175-190.

K. CHARACTERISTICS OF THE HUMAN LEARNER

This facet of the research program in psychology aims to understand the human system that we are trying to train to function effectively in Naval jobs. What resources does the human learner have available that can be worked with? There are three primary questions about the characteristics of this system:

* How is the information that is presented coded and stored for future use?
* What processes are available within the system to operate on that information?
* What are the mechanisms of control that govern the selection and operation of those processes?

These questions are generally recognized as important in experimental psychology, but there is a particular emphasis on developing those aspects of psychological theory that will help us to understand how the human system acquires and performs complex skills. A central challenge in this research is to factor out invariant structural characteristics of the human information processing system from modifications that learning builds upon those characteristics. In this way, we can achieve an understanding of sound bases for personnel selection and an understanding of the way in which desirable modifications of human abilities can be brought about. Research on the storage of information in short-term memory is suggesting how we can create new structural resources in the human system in order to enhance the ability to deal with complex and information-intensive tasks.

Much of the work in this cluster has focused on the spatial abilities that figure in many Navy jobs (e.g., aircraft control, surface operations, electronic maintenance). The approach contrasts with the traditional psychometric approach, instead aiming at a fine-grained understanding of available information processing operations. In addition to fine-grained analysis of individual differences, this research has aimed to determine the degree to which specific components of ability are trainable. This research should be valuable in selection and training and for the design of diagrams, job aids, etc., that will meet the needs of a wider range of personnel.

This research focuses on attentional allocation and capacity, with a view to understanding the abilities required to operate complex, high demand systems such as aircraft. The way in which appropriate training can reduce the effective attentional demands of complex tasks has been a major theme, which is already influencing more applied training research.

Work in this cluster is conducted with and passed to applied interests through both formal and informal conferences. Representatives of Navy laboratories, of other-service laboratories, and both military and civilian R&D managers are invited to these meetings. Meetings discussing the research of this cluster have been scheduled at Yale-Haskins Laboratory in March 1984, Harvard University in October 1985 and the University of Oregon in October, 1986.

COMPREHENSION PROCESSES IN MECHANICAL REASONING

NR 150-476
Carnegie-Mellon University/Just 6 Carpenter

Scientific Objectives: The major goal of the research is to provide an explanation of how people come to understand the workings of a mechanical device or machine by reading a technical text and inspecting an accompanying diagram.

Approach: This research will use a combination of techniques from experimental psychology and computer simulation. The experimental methodology involves the tracking of observers' eye fixations as they read technical texts and solve visual problems. The record of their points of regard in the display provides an index of the sequence and durations of the ongoing mental processes. Other behavioral measures collected are reaction times and patterns of errors in tests of mastery of the device. The computer simulation work involves the construction of production systems that perform the visual and mechanical tasks similarly to the humans, preserving the sequential and temporal patterns revealed by the eye fixations. The production systems will be written under CAPS, a parallel, activation-based, production system.

Progress: This project was begun late in FY-85, and no Status Reports have yet been received.

Potential Applications: The research may lead to new instructional technologies, involving gaze-contingent text and diagram displays, and animations of mechanical systems. The intent of these innovations is to optimize the match between the displayed information and the reader's state of thought at any given instant. In particular, this approach might be capable of instantaneously detecting "mental logjams" and assisting in their breakup.

Archival Publications:

Just, M.A., & Carpenter, P.A. (1985). Cognitive coordinate systems: Accounts of mental rotation and individual differences in spatial ability. *Psychological Review*, *92*, 137-172.

TRANSFORMATIONS OF SHORT-TERM VISUAL MEMORY

NR 154-533
University of Pennsylvania/Sternberg

Scientific Objectives: To investigate how visual information is represented in memory during the first few seconds after a display. Issues include how many representations must be postulated, when they are available, their properties, their durations, the transformation from one to another, and effects of the class of display elements. Unlike much previous research on these issues, this work employs arrays small enough so as not to overload memory; the aim is to understand performance under conditions of high accuracy.

Approach: By applying time pressure to the observer under these conditions we induce mechanisms to reveal themselves, not by how they fail, but by how much time they need to succeed. Thus, measures are taken of how much time a person needs to retrieve information accurately from memory of the display, and how this depends on time since display, number of displayed elements (e.g., alphanumeric characters, nameless shapes), information required, and probe type. A critical feature of the approach is the use of a range of d-values. (This feature seems essential since earlier work found that whether retrieval requires more or less time as the probe is delayed depends on d).

Progress: The research has developed and tested four diverse experimental paradigms that express the approach. All four produced orderly data that revealed sharp changes in the pattern of retrieval times -- and hence in the internal representation -- within about one second of the display. Among the more surprising findings were inverse effects of delay on search rates and reciting speed, rapid loss of direct access by location, functional equivalence of visual and tactile location markers, similarity of memory transformations for familiar symbols and unfamiliar nameless shapes, and an advantage of array over sequence even after several seconds.

Potential Applications: Knowledge of how visual information is assimilated is important in the design of displays and tasks. Particular findings with practical implications include effectiveness of tactile stimuli in directing visual attention, advantage of location over identity probes for large arrays, time costs of increasing array size for different tasks, and the advantage of presenting visual information arrayed spatially rather than sequentially for accurate, fast, and flexible use.

COPING WITH NOVELTY AND HUMAN INTELLIGENCE
NR 154-534
Yale University/Sternberg

Scientific Objectives: The goal of this research effort is to isolate the parameters of problem-solving performance that measure the ability to deal with novelty, particularly the ability to deal with relevant novelty in counter-factual (hypothetical) reasoning.

Approach: Converging operations are used in three domains and in multiple tasks within each domain to establish the construct validity of the operationalizations of the ability to cope with novelty in counterfactual reasoning. Internal and external validation are used to ensure both the satisfactory isolation of the relevant parameters, and the convergent and discriminant validity of the parameters with respect to established psychometric measures. By isolating the parameters that bear specifically on the ability to deal with novel problems, it will be possible to integrate a theory of this ability with existing ability theories derived from psychometric and cognitive research.

Progress: Four series of experiments have been completed and support in different ways the validity of an ability to cope with novelty in counter-factual reasoning. The experiments have elaborated the information-processing bases of this ability pointing out that it is not a unitary one. Rather, the ability involves component subskills requiring both comprehension of novelty and reasoning with the information comprehended.

Potential Applications: This work will contribute to the basic research foundations for personnel selection. In particular, it should contribute to our ability to select for individuals who can cope with the demands of novel situations.

INTELLIGENT MAINTENANCE TRAINING SYSTEM
NR 535-001
University of Southern California/Towne

Scientific Objectives: To develop an experimental training system for intelligent computer-assisted maintenance training that includes both (1) computer-aided methods for analyzing the practice requirements of maintenance training and (2) a general training system that will provide individualized selection and sequencing of exercises and an automated tutor that will coach students during exercises. This system will incorporate the Navy' s existing General Maintenance Training Simulator and will be implemented for blade fold rotor brake (helicopter) maintenance training.

Approach: Relations among training exercises and required skills will be represented in a database, constructed with computer-aided analyses. Artificial intelligence techniques will be used to model the acquisition of student skills, to select appropriate exercises, to analyze ongoing student performance, and to provide appropriate tutorial interventions.

Progress: A detailed planning study was completed. Internal data structures for the system have been specified. Editors to configure the system for particular applications were completed from four areas: (1) generic elements (replaceable units, indicators, and controls); (2) graphic system configuration; (3) student knowledge and skills; and (4) PROFILE (diagnostic expert system) data.

Potential Applications: It is anticipated that this system will allow an experienced maintenance technician to easily enter system-specific information to produce both training simulation and an automated intelligent tutor for any of a wide range of electrical, mechanical and hydraulic systems.

Reports:

Towne, D. M., Munro, A., Pizzinig, A., Surmon, D., and Johnson, W. B., (1985) Development of Intelligent Maintenance Training Technology: Design Study. Los Angeles, LA: University of Southern California, May, 1985.

Funding: NPRDC

INTERACTIVE ACTIVATION MODELS OF SPEECH PERCEPTION
NR 667-542
University of California, San Diego/Elman & McClelland

Scientific Objectives: Development of a model of human speech perception that is psychologically accurate in understanding the details of human speech perception experiments, and that is computationally adequate to recognize words and phonemes in real speech.

Approach: Interactive activation models are used as a theoretical framework within which to build models of speech perception. Interactive activation models are those in which processing is carried out by a large number of highly interconnected processing elements. A model of speech perception is developed in this framework and then applied to an analysis of a number of different issues in speech perception.

Progress: The interactive activation model of speech perception (TRACE) developed during the previous year's contract work has been extended by (a) addressing, by experimental means, the questions of how modular the speech perceptual apparatus is; and (b) developing a new technique for applying a "connectionist" solution to the problem of how human speakers (or machine analogs) might learn the knowledge structures necessary for recognizing speech.

Potential Applications: The basic interactive activation is potentially applicable to a wide range of Navy-relevant human behavior which has resisted analysis in terms of standard information processing approaches, especially in areas such as perception, automated response generation and decision-making under time pressure, etc. More specifically, the TRACE model of speech perception is a step toward the development both of an understanding of what is necessary for effective speech communication, thus aiding design of speech-production machinery, and an understanding of the basic principles at play in perception, thus aiding in the design of speech perception machinery.

FUNCTIONAL SYNERGIES IN VOLUNTARY MOVEMENT AND SPEECH
NR 667-509
Haskins Laboratories/Kelso, Saltzman, & Turvey

Scientific Objectives: The current project seeks to understand how the multiple degrees of freedom of the skeletomuscular system are organized to produce coordinated movement. Integrated with our experimental work involving discrete and rhythmical tasks is the further development of mathematical descriptions of such functional units and a description of their physical basis.

Approach: Kinematics (e.g., velocity), kinetics (e.g., torque), and related muscular activity are being measured in tasks that involve movement of (1) limbs, hands, and fingers, both singly and in concert and (2) speech articulators. Key experimental strategies: (a) apply perturbations to ongoing movements to identify functionally and remotely linked articulators and (b) systematically vary kinematic and kinetic parameters (e.g., frequency and inertia) to identify properties that remain invariant across transformation. Mathematical (task dynamical) models are being used to describe trajectories and compensatory behavior arising from both strategies, while a law-based account under development is used to rationalize invariant properties emerging from strategy (b).

Progress: The results of a series of studies provide strong evidence that the various muscles participating in an action function as a flexible unit to achieve a functional goal, despite external perturbations that disrupt the normal course of actions. There appear to be only a few stable phase relations in which the motions of two limbs can be combined. Properties of motion transitions have been shown to resemble properties of non-equilibrium phase transitions of chemical substances. A mathematical model has been developed to predict the natural rate of the combination of two motions with different natural rates.

Potential Applications: Knowledge of how functional units are formed and dissolved should provide a rational basis for understanding processes of skill acquisition (developmentally or in adults), skill loss (due to injury or aging), and the production of speech.

Archival Publications:

Kelso, J. A. S., V. Bateson, E., Saltzman, E. L. & Kay, B. (1985). A qualitative dynamic analysis of reiterant speech production; Phase portraits, kinematics, and dynamic modeling. Journal of the Acoustical Society of America, 77, 266-280.

Kelso, J. A. S. b Tuller, B. (1985). Intrinsic time in speech production. Journal of the Acoustical Society of America, 77 (Suppl. 1), S53.

Saltzman, E. L. (1985). On the coordination and regulation of complex sensorimotor systems (A review of H. T. A. Whiting (Ed.), Human motor actions; Bernstein reassessed). Contemporary Psychology, 30, 531-533.

Turvey, M. T., & Carello, C. (1985). The equation of information and meaning from the perspectives of situation semantics and Gibson's ecological realism. Linguistics and Philosophy. 8, 195-202.

LEARNING AND COORDINATION OF COMPLEX PSYCHOMOTOR SKILLS
NR 667-510
The Technion/Gopher
The University of Illinois/Donchin & Karis

Scientific Objectives: The aim is the study of the mechanisms and processes involved in the acquisition and operation of complex psychomotor skills.

Appraoch: A data-entry skill on a newly designed, two-hand chord keyboard was used as a model task. The keyboard contained two separate 5-key panels, each capable of producing the full set of letters. The performer was free to develop strategies of coordination, and in principle was capable of typing two different texts simultaneously. The system provided an interesting testbed for fundamental issues in the study of complex skills. Prototypes exist both at the Technion and at the University of Illinois, and experiments have been conducted in both the Hebrew and English languages.

Progress: Experiments were conducted with two types of tasks: entering sequences of single letters by one hand and pairs of letters by two hands, and typing free text with one or two hands. The main conclusions were: (1) Skilled movements are represented by general schemas that were separate from the direct parameters of the actual movement; (2) Schemas varied in their formatting elements, depending upon the coding principles that were used to encode them; (3) One store of representations served both hands; (4) The store had spatial composites and was localized in the right hemisphere; and (5) Responses to letter pairs that had to be typed simultaneously were searched and prepared for sequentially. A four-stage process of transcription emerged from these results. These were: letter identification, code retrieval, conversion to hand format, and execution of movement. Factors influencing processing efficiency were revealed both within and across stages.

Potential Applications: The results of this research suggest new possibilities for the design of data-entry and other kinds of manually operated controls. They also indicate the effectiveness of novel training procedures, using imagery, to help trainees learn to operate such devices quickly and efficiently.

Reports:

Gopher, D, Koenig, W. Karis, D, Donchin, E. (1984). An information processing approach to the study of data entry skills: The effects of representation rules and coordination requirements (Technical Report CPL84-14). Urbana, IL; University of Illinois, Department of Psychology, October 1984. (AD 150295)

ATTENTION AND PERFORMANCE
NR 667-523
University of Oregon/Posner
Washington University/Keele

Scientific Objectives: The objective is to test a theory which specifies the relationships between neural systems and elementary information-processing operations. The operations of interest underlie the control of visual attention, language comprehension, and the control of movement.

Approach: The research is using techniques for the analysis of the time course of attention control and movement coordination. These techniques produce measures of the speed and accuracy with which the subskills of attention and motor control are performed in a given individual. Measurements of these subskills are made for normal young adults and for various populations of individuals with brain lesions at particular sites. The resulting performance comparisons are being used to test a theory of attention and motor control which assigns particular information-processing activities to particular brain sites.

Progress: Research with normal and brain-damaged patients was carried out to identify the neural bases for the operations underlying the movement of attention in visual space. These studies revealed that (1) Unilateral lesions of the posterior parietal lobe produce a specific disruption of the ability to disengage attention from a prior spatial location in order to move it to new attention-demanding sites located in the contralateral visual field; (2) Lesions in the midbrain region affect the ability to move attention from its current fixation; (3) The movement of attention from a spatial fixation produces a reduced ability to immediately return attention to that fixation site; and (4) The neural mechanisms underlying movement of attention in visual space are distinct from, and hierarchically below, the more general mechanism of attention control that determines the modality to which attention is directed.

Potential Applications: This research seeks to identify and characterize certain fundamental information-processing operations underlying many Navy jobs, particularly those with high real-time attentional demands. The research will lead to better ways of assessing people's potential to perform these tasks and will provide better models for training in these tasks.

Archival Publications:

Posner, M. I., Choate, L. Rafal, R., and Vaughan, J. (1985). Inhibition of return; Neural mechanisms and function. Cognitive Neuropsychology 43, 2-11-228.

Posner, M. I. & Marin, O. S. M. (Eds.) (1985). Attention and performance XI: Mechanisms of attention. Hillsdale, NJ: Erlbaum.

Posner, M. I. (1985). Chronometric measures of "g": Commentary on A. R. Jenson's: The nature of black-white differences on various psychometric tests: Spearman' s hypothesis. The Behavioral and Brain Sciences, 8, 237-238.

Friedrich, F. J., Walker, J. A. & Posner, M. I. (1985). Effects of parietal lesions on visual matching: Implications for reading errors. Cognitive Neuropsychology, 213, 250-264.

SKILL AND SKILLED MEMORY
NR 667-549
Carnegie-Mellon University/Staszewski

Scientific Objectives: This research investigates how experts' efficient use of memory enables them to achieve exceptional performance on difficult and demanding tasks. Its goal is to identify and characterize the memory structures and processes that experts exploit to access information in an extensive knowledge base rapidly and reliably.

Approach: Studies focused on a small number of participants who developed expert-level cognitive skills through hundreds of hours of laboratory practice. Their skills are analyzed intensively using methodological tools that include protocol analysis, experimental hypothesis testing, and computer simulation modelling,

Progress: Two extended training studies investigate the nature and mechanisms of expert performance. In both, subjects practiced difficult cognitive tasks using strategies identified in prior analyses of established experts. In a memory training study an otherwise normal participant increased digit-span to 110 digits with over 800 hours of practice. Approximately 250 hours of mental arithmetic practice enabled two other participants to become expert "mental calculators" who can multiply large numbers with extraordinary speed and accuracy without recourse to external memory aids. These studies showed that experts capitalized on 1) mnemonic encoding, 2) retrieval structures, and 3) practice-related speed-up of encoding and retrieval processes to effectively expand their working memory capacity for materials within the domain of their expertise. Enhanced working memory, in turn, enabled the experts to overcome fundamental information-processing constraints and achieve exceptional performance.

Potential Applications: This work demonstrates that highly-motivated individuals with average abilities can achieve performance levels that most people assume require "special" or "exceptional" abilities. Further, detailed analyses of experts aimed at identifying both the general cognitive mechanisms and domain-specific strategies that support their performance can be used to develop effective procedures for training complex cognitive skills. Most importantly, the training studies show that the three principles of skilled memory -- mnemonic encoding, development and use of retrieval structures, and speed-up of encoding and retrieval processes through practice -- represent a basic set of design principles for the engineering of expertise in tasks whose memory demands severely constrain novices' performance.

VISUAL THINKING: AN EXPLORATION
NR 150-480/NR 667-480
Harvard University/Kosslyn

Scientific Objectives: This research is exploring new ways of studying the nature of the imagery processing system and new ways of testing theories about imagery representation and processing. The development of Kosslyn' s theory of the "processing modules" used in imagery is continued in order to discover how processing modules are realized in the two hemispheres of the brain,

Approach: Conceptual tools from computer science and methodologies from cognitive psychology and neuropsychology are used. In earlier work a computer simulation model that could mimic human performance in imagery tasks was constructed. This work is testing that theory by using it in a novel way; namely, to characterize patterns of behavioral deficits following brain damage.

Progress: Two patients who had the corpus callosum surgically severed, two aphasics, and a patient suffering from temporal-lobe amnesia have been tested in-depth. The theory successfully characterized the data. Two especially interesting results were obtained. First, the left cerebral hemisphere was superior to the right in some (but not all) imagery tasks; this finding is counterintuitive to many (the right hemisphere has often been claimed to be the seat of mental imagery) but was predicted by the theory. Second, the processing modules are not independent; damage can disrupt the ability to use two modules at once while leaving intact the ability to use them individually or in combination with other modules. In addition studies were made of processing in normal observers and a new computer-simulation model of imagery was developed. The new model was neurologically plausible, and was used to predict effects of brain damage, as well as data, from normal observers.

Potential Applications: First, results can guide construction of new psychometric instruments, allowing selection of personnel best suited for performing tasks requiring different sorts of imagery. Second, it is now feasible to train the specific imagery abilities, having characterized them well enough to design specific exercises. Third, this characterization of the human imagery system suggests ways of building computer-aided imagery systems, which essentially "externalize" imagery, allowing one to use a computer to circumvent weaknesses in the human system (e.g., its low capacity and resolution).

Reports:

Kosslyn, S.M., Cave, C. B., and Provost, D. (1985). Seguential processes in image generation: An objective measure (Tech Rep #6). Harvard U., Department of Psychology, September 1985.

Kossyln S.M. (1985). Visual hemispheric specialization: A computational theory (Tech Rep.# 87). Harvard U., Department of Psychology, September 1985.

THEORETICAL AND EXPERIMENTAL RESEARCH INTO BIOLOGICAL MECHANISMS UNDERLYING LEARNING AND MEMORY

NR 670-462
Brown University/Cooper

Scientific Objectives: The major goal of this project is to elucidate the biological mechanisms that underlie learning and memory. Experimental data on a cellular level are to provide a basis for functional organizations of large numbers of neurons that receive sensory and/or interneuronal information. This comprehensive program of research includes investigations of biochemical principles governing synapsic formation and modification, the dependence of learning on synaptic modification and organizational principles for neuron network models that can reproduce higher-level cognitive acts.

Approach· Analytical and experimental approaches are being employed in testing the implications of proposed theoretical mechanisms, and in examining the theoretical consequences of experimental results. Principles that appear to be operating on the cellular level are used to construct models of higher-level functions.

Progress: Ideas about synaptic modification, applied to visual cortex, gave results that agree with classical experimental data obtained during the last generation. Extensions of theory to a more realistic anatomy of visual cortex illuminated synaptic modification dependence on local information as well as on certain global properties, permitting further comparisons with experiment. Several experimental investigations of global controls were completed, including a study of the importance of activity in the norepinephrine system for learning during the critical period. Neural models were applied to psychological phenomena such as common associations, multistable perception, categorization, feature analysis, and abstraction. A model of language acquisition that can account for important aspects of grammar and language was developed.

Potential Applications: Knowledge of the basic processes by which the central nervous system learns and organizes itself will have important implications for computer science as well as for the understanding of cognitive processes, including various aspects of human learning and behavior.

Archival Publications:

Anderson, J. A. (1985). What Hebbs' synapses build. In W. Levy, S. Lehmkuhle, & J. A. Anderson (Eds.), Synaptic modification, neuron selectivity, and nervous system organization. Hillsdale, NJ: Erlbaum.

Bear, M. F., Carnes, K. M., & Ebner, F. F. (1985). An investigation of cholinergic circuitry in cat striate cortex using acetylcholinesterase histochemistry. Journal of Comparative Neurology, 234, 411-430.

Cooper, L. N., Munro, P. W., & Schofield, C. L. (1985). Neuron selectivity: Single neuron and neuron networks. In W. Levy, S. Lehmkuhle, 6 J. A. Anderson (Eds.), Synaptic modification, neuron selectivity, and nervous system organization. Hillsdale, NJ: Erlbaum.

Hohmann, C. F. Bear, M. F. & Ebner, F. F. (1985). Glutamic acid decarboxylase activity decreases in mouse neocortex after lesions of the basal forebrain. Brain Research, 33, 165-168.

NEURAL BASIS OF VISUAL PROCESSING ABILITY
NR 670-465
Harvard University/Kosslyn

Scientific Objectives: This research aims to revise an existing computational theory of visual mental imagery in order to incorporate neurophysiologically plausible parallel processing networks and to integrate the theory with a broader theory of "high level" visual information processing. Experimental studies will be conducted to isolate the brain locations that carry out the processing described in the theory.

Approach: The theory will be expressed as computer simulation models of the processing of high-level visual information. Experiments will be conducted with varying populations of brain-damaged individuals in order to determine whether the major information processing operations described in the theory can be localized to particular brain locations.

Progress: This work began late in FY-85, and no Status Reports have yet been issued.

Potential Applications: Spatial abilities are central for performance in many Navy tasks. This research can provide better understanding of the foundations of those abilities and a sounder basis for personnel selection.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

INDIVIDUAL DIFFERENCES IN STRATEGIES FOR PROCESSING SPATIAL INFORMATION
NR 150-469
University of Pittsburgh/Cooper

Scientific Objectives: The objective was to identify and to characterize alternative information-processing strategies that underlie the development of skilled performance on complex, spatial problem-solving tasks. A key hypothesis being investigated was that a number of strategy-related factors contribute to spatial skill: current repertoire of strategies, efficiency in using any strategy to which attention is directed, flexibility in selecting a strategy appropriate to the current problem-solving environment.

Approach: This project employed a combination of objective (time and accuracy measurements) and subjective (verbal reports) dependent measures. Overall accuracy in problem solving was measured as a function of complexity and structure of the spatial problems. In addition, the time spent inspecting different parts of the problem was measured, as was the number of times problem solvers alternate between different problem parts. Both retrospective and on-line verbal protocols were recorded from the participants in an effort to determine how they believed that they solved each problem. The convergence of all of these experimental measures was used as a basis for inferring the underlying strategies for performance.

Results and Conclusions: Two primary strategies for solving the spatial problems were isolated. One strategy, termed the "constructive" method, involves the visualization of a three-dimensional model of an object as a tool for reasoning about how two-dimensional parts of the structure should be combined. The second strategy, the "analytic" method, involves the comparison of corresponding two-dimensional parts of objects -- rather than the visualization of the object as a whole -- to determine local correspondences. Neither strategy seems to be associated in a simple manner with level of problem solving skill; however, the ability to switch from one strategy to the other, depending on the type of problem presented, as well as a rich repertoire of strategies from which to select, appear to be essential factors in achieving high levels of skill. Evidence was obtained that all participants report some three-dimensional, view-dependent information after exposure to problems presenting 2-D object depictions.

Potential Applications: The chief application of the findings is the development of techniques for enhancing the development of spatial skill in a training situation.

Reports:

Cooper, L. A. (1985). Strategies in processing spatial information: Relationships to spatial aptitude (Final Report) University of Pittsburgh, Department of Psychology, October, 1985.

Archival Publication:

Cooper, L.A., & Mumaw, R.J. (1985). Human spatial aptitude. In R. Dillon and R. Schmitt (Eds), Individual differences in cognitive processes. New York: Academic Press.

LEARNING FROM CONTEXT AND VERBAL ABILITIES
NR 154-505
Yale University/Sternberg

Scientific Objectives: The objective of the research under this contract was to understand the information-processing bases of verbal intelligence. What differences in mental processing distinguish highly verbally intelligent people from the less verbally gifted?

Approach: One set of experiments involved "task decomposition", i.e., inferring the mental processing people do in their handling of verbal materials in order to make sense of what they read. A second set of experiments involves development of measures that will pinpoint the sources of individual differences in people's verbal abilities. In other words, given an understanding of the mental representations and processes people use in understanding text and particularly new concepts embedded in these texts, how can one best measure differences in people's ability to deal with these new concepts? A third set of experiments involved training of verbal intellectual skills, and particularly, the skills involved in figuring out the meanings of unknown words.

Results and Conclusions: A fairly well-specified and useful theory of verbal comprehension was proposed and tested. Sets of experiments were completed that show (1) The theory of verbal comprehension provided a very good account of what it was that made some new words harder (or easier) to learn than others (task variance); (2) A way to measure individual differences in verbal comprehension in a way highly predictive of success in understanding verbal materials, as in standard verbal tests of intelligence, and (3) The training of verbal skills according to the parameters of the theory and increases in scores on tests of learning the meanings of words from context that was of the order of 30% over original test scores.

Potential Applications: This research has developed excellent measures of verbal comprehension abilities that can be used in assessment batteries for measuring verbal intelligence. These tests, unlike vocabulary tests typically used, do not suffer contamination from extensive differences in prior knowledge, which may have little to do with ability, but a lot to do with past opportunities. Moreover, it has developed a training program that can significantly and substantially increase people's skills in figuring out meanings of new words and concepts from natural contexts. This training program is important both in school and job training, as much of new learning in any field requires gaining an understanding of the language of the field. The training program emphasizes learning-to-learn skills, rather than just factual content, so that individuals can go on to apply the skills they learn in everyday environments.

Archival Publications:

Downing, C. J., Sternberg, R. J., & Ross, B. (1985). Multicausal inference: Evaluation of evidence in causally complex situations. *Journal of Experimental Psychology: General*, *114*, 239-263.

Sternberg, R. J. (1985). *Beyond IQ: A Triarchic theory of human intelligence*. New York: Cambridge University Press.

Sternberg, R. T. (1985). Implicit theories of intelligence, creativity, and wisdom. *Journal of Personality and Social Psychology*, *49*, 607-627.

Sternberg, R. J. (1984). A theory of knowledge acquisition in the development of verbal concepts. *Developmental Review*, *4*, 113-138.

L. INSTRUCTIONAL THEORY AND METHODS

Research in this cluster is devoted to the development of instructional theories that support both the design of advanced computer-based training systems and improvement of more traditional training methods. In 1985, an Accelerated Research Initiative, Cognitive and Technological Approaches to Navy Training, began to provide the resources to substantially expand this effort, with emphasis on relationships to naval needs in the area of remedial basic skills instruction.

Individual human tutoring has been shown to have large, positive effects on educational and training outcomes. Therefore, the possibility that artificial intelligence technology might be used to simulate the effectiveness of individual human tutors provides an attractive research goal. The problem of artificially intelligent computer-assisted instruction integrates many of the basic scientific concerns of the Personnel and Training research program: measurement and diagnosis of cognitive skill and knowledge, adaptation to individual cognitive abilities, and instructional strategies and tactics. Furthermore, intelligent tutoring systems are uniquely appropriate as laboratories for the analysis of complex human learning. The precise tuning and control of explanations and feedback in intelligent tutoring systems, along with detailed records of trainee performance, provides a novel opportunity for investigating questions of instructional theory and motivation in realistically complex learning situations. Many of the findings will be applicable to traditional classroom instruction, as well as to automated instruction, but the questions could never be effectively investigated in traditional classrooms.

Through the DoD-University Research Instrumentation Program (DURIP) and an associated contract, this cluster includes a community-building effort to provide selected university-based research efforts with a common set of computational resources for research on intelligent computer-based, instruction. This activity is intended to avoid duplication of effort by individual researchers and to more effectively focus research resources on questions of learning and instruction by minimizing technical computing problems.

Some of the individual contracts in this cluster address questions, also of concern to the computer science community, that are broadly significant for intelligent computer-based instruction, for example: how can knowledge be represented and structured in the computer in order to support the flexible generation of explanations? How can artificial intelligence approaches to learning be used to infer the student's state of knowledge and current rules of operation?

Other contracts focus upon learning and instruction in a wide range of tasks and skills which may present very distinct training problems. In some skills, such as air-intercept control, the pacing of external events demands a high degree of automaticity in cognitive functioning. Problem-solving skills such as those required for trouble shooting electronic devices or programming computers are quite different in quality. Attention is also being given to research issues relevant to basic skills in reading and mathematics, for which remedial training of Navy personnel is sometimes necessary.

Recent research on the cognitive requirements for such skills is discussed in Cluster M (Knowledge and Skill). That research and related work provide the basis for intelligent automation of tutoring, of generation of exercises and examples, and of other instructional functions. Another focus of contracts in this cluster has been on different forms of instruction to teach procedural skills, via text graphics, and computer displays. The procedural skills involved in equipment operation and maintenance are of particular concern in military training and have not been emphasized in other educational research on text design and readability.

To coordinate work in instructional methods and technology, we have been holding annual meetings, in which a[illegible] contractors informally brief each other on their latest work and plans [illegible] meetings typically include presentations by scientists outside t[illegible]m who are working on related problems, and presentations by military scientists investigating related but more applied problems. Selected representatives of other Navy, DoD, and federal agencies are invited to attend the meetings and participate in the technical discussions. Coordination efforts in this domain have proven successful within the Navy and elsewhere. More applied research and development in intelligent computer-assisted instruction that builds upon ONR research is now being pursued by MPEDC and NTSC as well as the AFHRL and NSF Science Education. In December, 1985 a special meeting of researchers doing work related to mathematics instruction (Cluster L and Cluster M) was held in San Diego to present information about a CNET-sponsored revision of the Navy's remedial mathematics curriculum by NPRDC. Meetings focused on text design and procedural instructions were held in June, 1984 at the University of Arizona and at Carnegie-Mellon in June, 1985. In March 1986, a meeting of researchers in intelligent computer-assisted instruction was held at the Xerox Palo Alto Research Center, attracting many representatives from industry as well as from the military R&D community.

A COMPUTER-BASED CONSULTANT FOR INTRODUCTORY COMPUTER PROGRAMMING
NR 154-492
Yale University/Soloway

Scientific Objectives: The intent is to develop a set of principles that can guide the construction of a key component of an Intelligent Tutoring System (ITS); namely, the component that can diagnose student responses and identify potential misconceptions. The issues that surround this key component are explored in the domain of computer programming. Thus, their immediate goal is to design, build, and evaluate a system that can diagnose a "buggy" computer program generated by a novice programmer, and provide an analysis of that program to the student.

Approach: A diagnostic system, PROUST, has been developed and classroom-tested. PROUST finds the non-syntactic bugs in students' programs and suggests misconceptions that may be causing those bugs. PROUST embodies a theory of how expert programmers find bugs and how novice programmers write programs. The key to finding bugs in a student's program is PROUST's ability to infer what goals the student was attempting to realize in the program.

Progress: PROUST was designed to analyze a class of moderately complex looping programs (between 40-60 lines of code) typically used in introductory programming courses. In classroom tests using actual student programs, PROUST accurately found approximately 75% of the bugs. This level of performance approached that of a human teaching assistant. Moreover, students who were given access to PROUST's analysis of their programs performed significantly better on examinations when compared with students who did not have access to PROUST's analyses.

Potential Applications: Computer programs are complex artifacts. The automation of the ability to analyze them and find non-trivial bugs is a significant accomplishment. The general approach taken by PROUST is not limited to the domain of computer programs. A PROUST-like system can be built to work in a wide variety of domains, e.g., debugging students' automotive repair strategies.

Archival Publication:

Johnson, W. L. & Soloway, E. (1985). PROUST: Knowledge-based program understanding. IEEE Transactions on Software Engineering. March.

COMPUTER MODELS OF OPPONENTS FOR TRAINING IN TACTICAL DECISION-MAKING

NR 154-486/154-502
Perceptronics, Inc./Chu

Scientific Objectives: The goal is to develop, implement, test, and refine a training system based on a cognitive model of expertise in time-stressed tactical planning.

Approach: Cognitive models are being adapted and extended for application to time-stressed tasks. Such tasks present unique demands for dynamic replanning and problem solving under multiple constraints. A Modified Petri Net representational framework is being used to formulate integrated solutions to several related problems in the representation and tutoring of dynamic skills.

Progress: An experimental computer-based testbed has been implemented to provide a simplified interactive simulation of the tactical surface warfare environment. The testbed system has been transferred to a LISP machine and has been upgraded to a nearly real-time simulation. An expert rule-based model has been developed for controlling ship maneuvers, radar/sensor selection, and use of chaff and missiles. The modified Petri Net (MPN) representational framework has proved useful in visualizing concurrent processes, representing multi-level action traces, and discovering diagnostic relations between classes of errors and situation-based rules.

Potential Applications: The modeling framework and testbed architecture can be applied generally to the development of training systems for time-stressed planning and decision-making tasks in both the military and civilian sectors. They can also be used in systems analysis. The use of such systems reduces the demand for human agents to play supporting roles in multi-agent simulations.

Funding: NTEC

DEVELOPMENT OF COMPUTER-BASED INSTRUCTIONAL SYSTEMS FOR TRAINING ESSENTIAL COMPONENTS OF READING

NR 154-519
BBN Laboratories/Frederickson

Scientific Objectives: The objective is to develop and evaluate instructional methods for training critical components of reading skill. Computer-based instruction incorporates continuous dynamic monitoring and feedback to develop and automate efficient decoding and comprehension procedures. A final objective is to extend interactive reading theory to include the high-level skills needed for analyzing cohesive features of text.

Approach: The instructional approach follows an analysis of reading in terms of skill components that are functionally interrelated. Components selected for training are those that have a broad impact on reading performance and that present particular problems for low-ability adult readers. Training is component-specific, including immediate feedback on efficiency and accuracy of performance. Where there are hierarchical interactions among components, training of lower-order components precedes training of higher-order components, and integration of skills is explicitly built into the later learning exercises.

Progress: Based on related research on controlled vs. automatic components of cognitive skill, computer-based systems have been developed for training reading-skill components in low-ability adult readers. These training systems incorporate advanced graphics, synthesized speech, and individualized instructional monitoring. Graphic feedback on performance and progress is a central design feature. Experimental evaluations of the training systems have been used to improve their design, as well as to gain more detailed knowledge of the structure and acquisition of reading skills.

Potential Applications: The instructional methods developed will be useful in remedial training programs, and can also be applied in any area of training in which automaticity of skill components is essential to effective high-level performance.

Funding: NPRDC, Manpower R&D Programs.

COGNITIVE PRINCIPLES FOR INSTRUCTIONAL DESIGN

NR 154-522

University of California, Berkeley/Reif and Heller

Scientific Objectives: The aim is to formulate and test theoretical principles for designing instruction. These principles are based on analyses of the underlying thought processes leading to good performance on complex intellectual tasks.

Approach: Explicit instructional models are formulated and then translated into detailed computer-based teaching programs. Individual subjects are observed before, during, and after interacting with these programs, while some of their verbalized thought processes are tape-recorded. These observations are used to assess the effects of particular features of the instructional models. Analysis of these data leads to refinements of the instructional programs and of the underlying theoretical models upon which they are based.

Progress: Preliminary teaching models have been developed in the following three domains: (1) Teaching the concept "acceleration" (to study the importance of procedural knowledge for interpreting scientific concepts); (2) teaching a procedure for describing the forces acting on an object (to study the human control processes needed to perform a complex procedure); and (3) teaching a computer operating system (to study the role of knowledge organization in learning). Assessment instruments have been developed for probing a participant's ability to interpret the concept "acceleration." Prototype computer programs have been developed. for teaching "acceleration" and force-description procedure.

Potential Applications: Because the design is systematic and principled, based on analyses of underlying human information processing, the instruction promises to be effective and applicable to classroom teaching as well as to the development of instructional computer software.

Archival PublicationS:

Reif, F. (1985). Acquiring an effective understanding of scientific concepts. In L. H. West & A. L. Pines (Eds), Cognitive structure and change (pp. 133-151). New York: Academic Press.

IMPASSES: KEYS TO A UNIVERSAL THEORY OF THE ACQUISITION AND MENTAL REPRESENTATION OF COGNITIVE SKILLS
NR 154-535
Xerox Palo Alto Research Center/Brown
Carnegie-Mellon University/Van Lehn

Scientific Objectives: this goal is to extend the theory of the learning expressed in the computer program Sierra, by testing two new hypotheses: that learning occurs when students reach impasses in their problem solving procedures, and that procedural skills are best considered as grammars to the interpretation of special notations. The validity of these hypotheses will be tested across several content domains in mathematics and science.

Approach: The computer program Sierra will be modified to incorporate the two hypotheses above. The modified program will be used to generate predictions of student behavior under various versions of the theory. These predictions will be tested against an existing database on students' learning of arithmetic procedures. A series of instructional experiments will be conducted, systematically varying instructional materials to test specific hypotheses underlying the theory of learning.

Potential Applications: Much of Naval training is concerned with teaching procedural skills. Previous work by these investigators has uncovered new conditions on the effective design of instructional materials, especially the content and sequencing of lessons.

Progress: This is a new contract, and no Status Reports have yet been issued.

NETWORK FOR RESEARCH ON INTELLIGENT COMPUTER-BASED TRAINING
NR 667-524
University of Pittsburgh/Lesgold
LISP MACHINES FOR INTELLIGENT COMPUTER-BASED INSTRUCTION
NR DIP-252
University of Pittsburgh/Lesgold

Scientific Objectives: The goal is to accelerate the progress of instructional theory for intelligent tutoring by establishing an interacting research community focusing cognitive research efforts on possibilities for intelligent computer-based training. These projects provide training, consulting, software tools, examples, and appropriate computer systems, freeing participating laboratories to focus on development and testing of instruction and training principles relevant to computer-based training.

Approach: Facilities are provided for sharing of software, problems, approaches, and research results among the projects involved in this work. Consulting help and training workshops are available for cognitive scientists who are, for the first time, going to be managing their own powerful computer systems and having to deal both with an extremely rich intelligent graphics programming environment and with issues in network communications, maintenance, and systems-programming aspects of the Interlisp-D environment. Tools, such as simulation languages and core utilities for intelligent tutoring systems, are being developed, together with portable training packages for those tools.

Progress: A set of supplementary manuals for the Interlisp-D language has been developed and circulated to the other laboratories. The "Friendly Dandelion Primer" developed here has become part of Xerox's documentation distributed with its machines. Workshops have been held to introduce other laboratories and DoD personnel to the Interlisp-D environment. Newsletters and a phone consulting service have been implemented. Hardware has been installed and upgraded at eight other sites. Examples and tools for window/menu oriented programming have been developed and distributed. Videotape-plus-computer-lab-environment training packages have been distributed to other sites. Additional workshops have been held and are planned. Portable packages are in development. Work on specific tutors is well underway under various funding auspices. The newsletter has been sent frequently to an expanding list of recipients. Visiting scholars from US and abroad have been trained and have contributed to the project perspective on ITS. Work on an object-oriented approach to ITS curriculum promises increased modularity and coding efficiency.

Potential Applications: Increased levels of research on how to construct effective intelligent training systems (coaches, tutors, and exploratory environments) will potentiate better future training approaches. This project aims to accelerate and focus the activities of more specific ventures.

Funding: ARI, AFHRL, NSF, NIE

Archival Publication:

Bonar, J.G. (1984). Cognition based intelligent tutoring systems. In G. Salvendy (Ed.), Human-Computer Interactions. Amsterdam: Elsevier Science Publishers B.V.

DESIGN OF INSTRUCTION MATERIALS FOR OPTIMIZING SKILL LEARNING
NR 667-529
Carnegie Mellon University/Reder-Charney

Scientific Objectives: The primary objective of the first two years was to develop a formally specified model of how particular kinds of elaborations of text content affect participants' behavior on specific tasks. The first goal was to establish that elaborations in an instruction text facilitate skill performance, in contrast to the detrimental effect elaborations have previously been found to have on fact learning. The second goal was to explore what types of information benefit from elaboration and what forms of elaboration are most effective.

Approach: Various versions of a computer manual are compared experimentally to determine how well they help participants acquire and perform a cognitive skill: learning to use a personal computer. Some of the studies also manipulate how effectively participants can generate their own task-specific elaborations when given advance information about the tasks they will have to perform on the computer. On-line data-gathering is used to measure how well participants perform tasks on the computer (without having the manual to refer to), and how efficiently they work (e.g., how much time they spend working on a task and how many steps they take).

Progress: Four studies on elaborations have been completed. The findings of the first two studies indicate that regardless of whether elaborations are provided in the manual or generated by the reader, they do facilitate skill performance. However, participants who knew about the tasks in advance performed better if they read the shorter, unelaborated version of the manual. Results from the third study suggest that while both expert and novice computer users benefit greatly from elaborations on the exact syntactic form required to carry out a procedure, neither group benefits when conceptual points are elaborated.

Potential Applications: By gathering experimental evidence about what kinds of elaborations facilitate skill learning for various kinds of learners, this research will provide useful design principles to writers of instructional materials.

Reports:

Reder, L., Charney, D., & Morgan, K. (1985). The Role of Elaborations in Learning a Skill from an Instructional Text (Tech. Rep. 1). Pittsburgh, PA: Carnegie-Mellon University.

Reder, L. (1985). Strategy Selection in Question-Answering (Tech Report ONR-85-2). Pittsburgh, PA: Carnegie-Mellon University.

Reder, L. (1985). Beyond Associations: Strategic Components in Memory Retrieval (Tech. Report ONR-85-3). Pittsburgh, PA: Carnegie-Mellon University.

ACQUISITION AND INSTRUCTION OF PROGRAMMING SKILLS
NR 667-530
Carnegie-Mellon University/Anderson

Scientific Objectives: The objective is to understand how LISP programming skills are acquired and how they can be taught effectively. The study of this skill is being used to test Anderson's learning theory.

Approach: Computer simulation models based on Anderson's theory are developed to account for the learning and problem-solving protocols. Based on the structure of these models, computer-based tutorial systems are developed for teaching the skills. These tutorial systems are then varied to explore issues in the learning theory and the theory of instruction. Use of tutorial systems as an experimental tool has enabled novel tests of issues of skill acquisition which extend over tens of hours.

Progress: In addition to simulating student protocols, a series of experiments has been performed to test and advance various aspects of the theory. A major effort has gone into converting the predictions of the theory into the design of an intelligent tutor for teaching LISP. The LISP tutor has been developed to the point where it exposes the student to about 15 hours of instruction and covers most of the major programming constructs in LISP. In preliminary evaluations the tutor has been shown to be as effective as human tutors and much more effective than traditional classroom instruction.

Potential Applications: The methods developed in this research effort can be extended to other programming languages like ADA. More generally, there is the potential for extending the methodology to teaching many technical skills.

Reports:

Anderson, J.R., (1985). Skill Acquisition: Compilation of weak-method Problem solutions (Tech Rep. ONR 85-1). Pittsburgh: Carnegie-Mellon University.

Archival Publications:

Anderson, J. R. (1985). Production systems, learning and tutoring. In D. K, Klahr, P.W. Langley, & R. Neches (eds.), Self-Modifying Production Systems: Models of Learning and Development: Bradford Books/MIT. Cambridge, MA, 1985.

Anderson, J. R., Boyle, C. F., & Reiser, B. J. (1985). Intelligent tutoring systems. *Science*, *228*, 456-467.

Anderson, J. R. & Jeffries, R. (1985). Novice LISP errors: Undetected losses of information from working memory. *Human Computer Interaction*, *1*, 107-131.

Anderson, J.R. & Reiser, B.J. (1985). The LISP tutor. Byte, *10*, 159-175.

Lewis, M.W. & Anderson, J.R. (1985). Discrimination of operator schemata in problem solving: Procedural learning from examples. *Cognitive Psychology*, *17*, 26-65.

Reiser, B.J., Anderson J.R., & Farrell, R.G. (1985). Dynamic student modeling in an intelligent tutor for LISP programming. *Proceedings of IJCAI-85*, 8-14.

Singley, K. & Anderson, J.R. (1985). The transfer of text-editing skill. *Journal of Man-Machine Interaction*, *22*, 403-423.

APPLYING ACTIVATION THEORY FOR MODELING TASK INTERFERENCE IN DUAL-TASK SITUATIONS

NR 667-546
University of California, San Diego/Norman and Navon

Scientific Objectives: The goal is to evaluate the ability of activation theory to explain phenomena of dual-task interference. Such phenomena have previously been attributed to "limited attentional resources."

Approach: A new experimental method, the optimum-maximum method, will be used to attempt to eliminate certain anchoring artifacts which can be created by traditional methods. This new method will be refined and used to provide rigorous tests of the relative merits of activation versus resource-limitation theory.

Progress: This is a new contract, and no Status Reports have yet been issued.

Potential *Applications*: Activation theory is a type of Parallel-Distributed Processing (PDP) modeling framework. PDP models can be applied to the design and engineering of special-purpose computing architectures for perceptual information processing and motor control. For example, such architectures could be applied to the design of innovative robotics systems.

A COMPUTERIZED COMPREHENSIBLE WRITING AID

NR 667-547
University of Michigan/Kieras

Scientific Objectives: The objective is to continue the work in a previous project (NR 667-513) to develop a computer-based system that will help technical writers prepare more comprehensible technical documents.

Approach: A previous demonstration system -- using natural-language processing techniques from artificial intelligence and research results from psycholinguistics to identify problems in technical documents that will produce comprehension problems for the reader -- is being upgraded and extended to include a more sophisticated parser, and more detailed comprehensibility rules.

Progress: The system is being developed on Xerox 1108 LISP machines, and a basic development environment has been implemented to make the construction of more complex grammar easier to do. A more elaborate system will be incorporated to yield a prototype version of the system. This system will be evaluated to see if its output is useful to actual technical writers.

Potential applications: This project is directly oriented toward developing the prototype for a fieldable system to aid technical writers.

DESIGNING AND IMPLEMENTING AND "INTELLIGENT" MULTIMEDIA TUTORING SYSTEM FOR REPAIR TASKS

NR 702-001
University of Colorado/Baggett

Scientific Objective: The intended end product of this research project is an "intelligent" multimedia tutoring system for procedural tasks, and more specifically, for assembly and repair of physical objects. By multimedia is meant moving video (from videodisc), still pictures and computer graphics, and spoken and written text, all combined with hands-on practice by the user. The main goal is to find the theoretical and practical principles for good multimedia instructional design, focusing on and i"ntelligent" interactive computer system, while also actually developing such a system.

Approach: The theoretical framework guiding this work concerns how people process information. It deals with concept formation and with encoding, retaining, and using information from multimedia stimuli. Within the - framework, a concept is represented as a graph with two kinds of associative links (subconcept and pointer), and five types of nodes, corresponding to elements from different modalities, i. e., mental, abstract, motoric (action), visual (pictorial), and linguistic. The method of research is to build an experimental implementation using the data structures and procedures acting on them which are presented in Technical Report 142-ONR.

Progress: 1. In the first phase of the research, participants were given four problems, or tasks. The data analysis found what the ''natural'' queries of subjects are when they are given a task. Information access was then designed to maximize the success rate and minimize collisions, using characteristic elements in the participants' queries as access keys. The technique, based not on semantics but on simple pattern matching, seems to be able to provide fast access to large data bases. 2. Using a prototype multimedia workstation on loan from IBM, we have run our first experiment on assembly. The interactive presentation combines videodisc, graphics, and speech as output. Subjects manipulate what they see using touchscreen only as input. They build an object during the presentation and then again from memory. The main advantage we observe thus far to interactive multimedia instructions over passive video is time to work when working from memory. Overall, subjects work less than 70° as long after interactive instructions. 3. We are just beginning research into designing our first "intelligent" multimedia presentation for repair tasks.

Potential Applictions: This work should lead to the formulation of theoretical and practical principles for designing interactive multimedia instructions for procedural learning. Also, an "intelligent" multimedia computer system will be developed, which can be used as a prototype in training situations.

Reports:.

Baggett, P. and Ehrenfeucht, A. (1985). Conceptualizing in Assembly Tasks. (Technical Report 139). The University of Colorado, Department of Psychology, April, 1985.

Baggett, P. and Ehrenfeucht, A. (1985). A Multimedia Knowledge Representation for an Intelligent Computerized Tutor (Technical Report 142). The University of Colorado, Department of Psychology, April, 1985.

FLEXIBILITY IN JOINT PROBLEM SOLVING: THE EFFECTS OF DIFFERENT POINTS OF VIEW ON OVERCOMING BLOCKS

NR 702-002
University of San Diego/Levin

Scientific Objectives: This work unit is a continuation of work begun under NR 667-532. The goal continues to be the specification of the role that conceptual points of view play in problem solving, especially when a problem solver is blocked (i.e., does not know how to take the next step).

Approach: Computer-based graphics microworlds have been developed as an instructional and experimental environment for the study of problem-solving skills. These micro-worlds allow the experimental manipulations of point of view as well as the measurement of changes in point of view during problem solving.

Progress: This is a new contract, and no Status Reports have yet been issued.

Potential Applications: Results will be useful in development of practical problem-solving aids and intelligent automated tutoring systems to teach problem-solving skills.

COMPUTER-BASED TUTORS FOR EXPLAINING AND MANAGING THE PROCESS OF DIAGNOSTIC REASONING

NR 702-003
Stanford University/Clancey

Scientific Objectives: The hypothesis under investigation is that a diagnostic procedure can be represented separately from the device-specific model it operates upon, and such a procedure can be used to simulate expert problem-solving behavior, generate explanations of reasoning for a student, and serve as a baseline for modeling student performance.

Approach: A family of tutoring programs is being constructed that will enable a student to watch, explain, debug, and learn in apprenticeship the process of diagnosis. These programs are built upon an expert-system shell, called HERACLES, that solves problems by the heuristic classification method. Modeling and explanation programs relate the student's behavior to the idealized model, attempting to sort out discrepancies in domain knowledge from discrepancies in problem-solving strategy. Synthetic students (systematic variations to the ideal model) and experiments with actual students are used to develop modeling capabilities. The family of tutoring programs systematically explores the advantages of different scenarios for learning (for example, critiquing another student's explanation versus completing a partial solution), allowing determination of how these activities might be sequenced and combined.

Progress: A medical diagnosis program, called NEOMYCIN, has been developed that performs well on a set of test problems to be used in teaching. The generality of the diagnostic model has been demonstrated by implementation of a prototype program for diagnosing defects in iron cast in sand. The first tutoring program, GUIDON-WATCH, incorporating strategic explanations and extensive displays of reasoning, is operational and being tried with students. A second generation modeling program, called ODYSSEUS, is partially implemented; it can recognize alternative but non-optimal paths of reasoning, and interact with the student to diagnose the cause for discrepancies in behavior. A new explanation program now under development uses a model of the user domain knowledge and improved implementation of the diagnostic strategy to more selectively mention facts used in reasoning. GUIDON-DEBUG, a program that allows a student to critique and improve someone else's solution, is in the early stages of implementation.

Potential Applications: HERACLES provides a general framework for representing experiential knowledge (contrasted with device simulation models) in an expert consultation system, with advances in ease of system construction and modification, and improved explanation over simpler rule-based approaches. The heuristic classification model is applicable to a wide variety of diagnostic, monitoring, repair, and planning problems.

Reports:

Clancey, W.J. (1985). Review of Sowa's "Conceptual Structures" (Tech. Rep. ONR-TR-11). Stanford University.

Clancey, W.J. (1985). Heuristic Classification (Tech. Rep. ONR-TR-12) Stanford University.

Clancey, W.J. (1985). Acquiring, Representing, and Evaluating a Competence Model of Diagnostic Strategy (Tech. Rep. ONR-TR-13). Stanford University.

Clancey, W.J. (1985). GUIDON-WATCH: A Graphic Interface for Viewing a Knowledge-based System (Tech. Rep. ONR-TR-14). Stanford University.

EXPERT PLANNING PROCESSES IN WRITING
NR 702-005
Carnegie-Mellon University/Hayes

Scientific Objectives: The goal is to refine and test a general theory of the cognitive processes underlying writing, especially processes of goal setting, goal management, and planning. The work aims to specify the subprocesses of planning (goal setting, goal generation, and organization) and to determine how novice and expert writers differ in their ability to adapt, develop, and revise their plans during the writing process.

Approach: A series of experiments is being carried out, using innovative methods of eliciting planning protocols from novice and expert writers. Different participants performance will be compared on identical complex planning tasks in order to isolate planning skills from other writing skills. Expert and novice plans will be compared at several different theoretical levels, ranging from global to very specific.

Progress: This is a new contract, and no Status Reports have yet been issued.

uPotential Applications: To deal with the increased demand to teach highly technical skills to technically unsophisticated trainees, both the criteria for training material and aids for writers need to be based on a sound theory of the writing process itself. The results of this research will clarify the processes involved in planning, organizing, and generating effective instructional materials for technical tasks.

LEARNING AND TEACHING IN THE CONTEXT OF MULTIPLE KNOWLEDGE SOURCES
NR 702-006
University of California, Irvine/Kibler

Scientific Objectives: The goal is to test a computational theory of the knowledge structures and processes associated with naive problem solving, expert problem solving, acquisition of problem-solving skills, and instruction of such skills.

Approach: A computational model has been designed for the knowledge structures and cognitive processes underlying skill and skill acquisition in the domain of algebra word-problem solving. The computational model rests on a number of testable hypotheses about what problem-solving skill is and how it can be learned. These hypotheses are being tested by means of psychological experiments and computer simulations. Central to the model are hypotheses about problem understanding, particularly the use and integration of multiple knowledge sources.

Progress: This is a new contract, and no Status Reports have yet been issued.

Potential Applications: Current teaching in mathematics and science is not founded on any rigorous model of learning. The present work proposes such a theory. To the extent that this theory is verified experimentally, it will contribute to better design of methods for instruction and assessment in technical domains which depend on mathematical problem solving.

TUTORING EXPERTISE: HUMAN AND COMPUTER
NR 702-007
Yale University/Soloway

Scientific Objectives: The goal is to test a computational theory of the knowledge structures and processes associated with expert tutorial skill in the domain of computer programming. A model for the diagnostic reasoning tutorial planning skills of effective human tutors will be used to create principles for the design of more effective intelligent tutoring systems.

Approach: A theory of plan coordination and plan integration is being tested in the domain of introductory Pascal programming. Methodology includes computer simulation of human performance, protocol analysis of human-human tutorial dialogues, and the analysis of a database of thousands of student programming examples.

Progress: An intelligent tutoring system for the Pascal programming domain has been implemented and is currently being tested in actual classroom settings. In a recent test, students who had access to the intelligent tutoring system showed measurable gains in terms of "bugs" eliminated from their programs and in mid-term grades, as compared with a control group matched for number and type of "bugs" initially present.

Potential Applications: The general plan-integration model underlying this research is applicable to many domains other than computer programming. It can be applied to any problem-solving or design domain in which complex performance produces great individual variability due to the need to integrate different plans and goals into a single solution or design, These domains range from architecture to circuit design to tactical planning.

Report:

Soloway, E. (1985). A computer-based consultant for introductory computer Programming. New Haven, CT: rale University, Department of Computer Science.

Archival Publications:

Johnson, W., Soloway, E. (1985). PROUST: Knowledge-based program understanding. IEEE Transactions on Software Engineering. (March).

Johnson, W., & Soloway, E. (1985). Automatic bug-detection. Byte (April).

SCHEMAS IN PROBLEM SOLVING: AN INTEGRATED MODEL OF MEMORY, LEARNING, AND INSTRUCTION

NR 702-010
San Diego State University/Marshall

Scientific Objectives: The project has two goals: (1) to examine the components of basic schemas used in solving simple arithmetic story-problems and (2) to develop instructional procedures that facilitate the development of these schemas in novice and/or unsuccessful remedial problem solvers.

Approach: Mental models of schema creation and use will be developed. These in turn will form the basis of computer simulations of learning. Additional tests of the models will come from implementation of the theory and related materials in a remedial junior-college class.

Progress: This research has just begun (September 1985). Preliminary studies appear to have identified a relevant set of basic schemas. Work is under way to determine whether that set is also sufficient to cover all arithmetic story-problems.

Potential Applications: The research will contribute to understanding of the knowledge structures used by students to solve story problems. It will also provide a theoretically-based system of instruction to develop the necessary structures. This should be of interest in the Navy's Remedial Mathematics Training of recruits.

THE IMPACT OF AN INTELLIGENT COMPUTER-BASED TUTOR ON CLASSROOM SOCIAL PROCESSES: AN ETHNOGRAPHIC STUDY

NR 702-013
University of Pittsburgh/Schofield

Scientific Objectives: The goal of this project is to assess the impact of the introduction of an intelligent computer-based tutor on classroom structure and functioning. Particular attention is being paid to issues such as (a) the new demands which this innovation places on students and teachers, and (b) how both students and teachers react to these demands.

Approach: An intensive ethnographic study of classes which use the intelligent computer-based tutor, and similar classes which do not, is being carried out. The two basic data-gathering tools are qualitative observation in these classrooms and repeated interviews with both students and teachers. Since observations were also made before introduction of the computer-based tutor both longitudinal and cross-sectional comparisons are being made.

Progress: In the few months since work began, we have gained access to all classrooms necessary for the study and begun weekly observations. Sampling of students and teachers for the interview panels has been completed and the student interview instrument has been developed and is now being pretested. Developmental work on the interviews with teachers is also well underway.

Potential Applications: Findings should be of considerable use in suggesting effective and efficient ways of utilizing intelligent computer-based tutors in classroom settings.

ENHANCING INCREMENTAL LEARNING PROCESSES WITH KNOWLEDGE-BASED SYSTEMS
NR 702-016
University of Colorado/Fischer

Scientific Objectives: This research effort aims to understand, how people incrementally learn to be expert in operating complex systems, and how they can be assisted in becoming more expert in the course of their operational experience. The particular case of computer systems for knowledge-based AI programming will be investigated.

Approach: Increasingly complex subsets of knowledge used in operating a complex knowledge-based computer system will be defined based upon records of user behavior. AI inference techniques will be used to diagnose user expertise in those terms. Building upon an existing AI system that can suggest improvements in LISP code, instructional interventions designed to improve system knowledge will be attempted and tested for their effects on subsequent performance.

Progress: This is a new contract, and no Status Reports have yet been issued.

Potential Applications: This research should yield insights into the way many complex computer-operated systems in the military could be designed to provide automated, embedded on-the-job training to bring operators to full skill levels.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

BASIC PROCESSES AND INDIVIDUAL DIFFERENCES IN UNDERSTANDING AND USING INSTRUCTIONS

NR 154-461
Bolt, Beranek and Newman, Inc./Smith & Spoehr

Scientific Objectives: The goal was to examine individual differences in the comprehension and use of written instructions for procedural tasks. Critical questions included: (1) Is there an optimal order in which to mention the various topics in a step? (2) Are different ways of organizing a fixed set of steps best for different types of tasks?

Approach: Participants executed procedural instructions about operating a control panel. They executed the instructions one step at a time and dependent measures included the time to read the instruction, the time to execute it, and the accuracy with which it was executed. The major independent variable was the order in which the various topics in a step are mentioned, e.g., either the main action is given first or topics are mentioned in the order in the main action is given first or topics are mentioned in the order in which they will be needed during execution. Other independent variables included the amount of practice subjects have with a particular order of topics and individual differences in subjects' working memories.

Results and Conclusions: Results showed that, because information from a step is comprehended by fitting it into a plan for carrying out the step, the optimal order of presentation for material in an individual step is the order in which the material is needed when the step is executed. Subjects are able to develop facilitative reading strategies for non-optimal wordings of steps if given sufficient practice. In addition, it appears that some of the individual differences in understanding instructions may be due to differences in the capacity of working memory. Having learned a "mental model" for a device facilitated memory about device components, instruction reading time, and ability to reason about the device.

Potential Applications: Findings about the optimal order in which to mention the topic in a step may lead to general guidelines for the construction of instruction manuals, or perhaps more significantly, the structure of instructions delivered by automated maintenance aids, such as the Army's PEAM system. Findings about individual differences in working memory could lead to a diagnostic for determining how well different people will do in different kinds of tasks.

PRINCIPLES OF INTELLIGENT COMPUTER-BASED INSTRUCTION FOR BASIC SKILLS
NR 154-497
University of Pittsburgh/Greeno & Brown

§uScientific Objectives¶u: The goal of this project was to identify, formulate, and evaluate principles of instructional design based on research in cognitive science. Attention was focused on two general topics: instruction of basic skills, and acquisition of knowledge for representing problems.

°§u)roach¶u: Results of cognitive analyses of instructional tasks were used in developing instructional systems. The research included development of learning tasks and implementation of the tasks in computer-based instructional systems. The tasks focused on significant components of cognitive skill that usually are embedded implicitly in instruction. Participants were observed working on these learning tasks, and conclusions were reached about acquisition of the skill components that have been identified in the cognitive analyses.- The number of participants was small -- usually 5-10 -- observed intensively with recorded protocols. Participants in studies of algebra included both middle-school students and adults recruited from college-age students having difficulty in an elementary course.

§uResults and Conclusions¶u: The existing designs of intelligent tutors were extended to incorporate new aspects of cognitive skills. One example is the cognitive structure of a procedure. Rules and strategies for problem-solving in algebra were taught in a task of transforming arithmetic expressions. The structure of the tutorial system focused on basic cognitive skills of applying operators correctly, rather than general strategies. Another example is knowledge for representing problems. A graphics system was used by students to create explicit representations of the quantities in word problems, and the compositional relations among those quantities. Learning to use the system, students reached a deeper understanding of relations between formal algebraic notation and concrete quantitative structures. Progress was also made on processes of reflection on a problem-solving record, and relations between concepts and problem-solving operations.

Potential Applications: At a general level, these results provide examples of ways in which results of cognitive research can be translated into instructional materials. The analyses of tasks in algebra and statistics identified specific cognitive processes needed for successful learning, and instruction focused on those processes has been designed. Similar analyses in other domains should be made easier by the availability of these results. More specifically, the instructional systems developed for training basic skills and representational knowledge in algebra could be reimplemented into instructional materials for basic mathematical training in the military or other educational settings.

Report:

Greeno, J. G., Brown, J. S., Foss, C., Shalin,V., Bee, H. Y., Lewis, M.W, & Vitolo, T.M. (1985). Cognitive Principles of Problem-solving and Instruction (Final Report). Pittsburgh, PA: University of Pittsburgh, Psychology Department.

OPTIMAL STRUCTURES FOR MULTIMEDIA INSTRUCTION

NR 154-500
SRI International/Goguen

Scientific Objectives: The goal was to produce effective multimedia instructional material, particularly computer-based material, by using experimentally verified principles for choosing among the many possible instructional approaches permitted within interactive visual and verbal media.

Approach: The research paradigm was a combination of experimental psychology, discourse analysis, and semiotics (the formal theory of sign-systems). Psychological procedures were used to examine the effects on comprehension and learning,of varying explanation strategies. Linguistic methods were used to describe the structure of explanatory discourse. Semiotic theory was used to describe the mathematical relations among different representational systems in an instructional situation, such as spoken and written language, charts, diagrams, devices and simulations.

Results and Conclusions: The major findings include the following: Choice of discourse type can strongly affect comprehension in ways that would not be predictable from other existing theories of instruction or discourse. Visual icons can greatly aid comprehension even in the absence of optimal coordination with verbal instructions. Manipulation of fine-grained discourse structure has significant and systematic effects on learning. The design of computer graphics should parallel the structure of successful naturally-occurring multimedia interaction, using integrated, hierarchically-structured icons with a rich set of indices into and out of the task domain, with clearly marked boundaries.

uPotential Applications: These results are applicable to the design of multimedia explanations of technical subjects, including videotaped demonstrations by a human tutor and computer and simulation-based training. Other applications include the design of natural-language and interactive graphical human-computer interfaces for intelligent tutoring systems and on-board fault diagnosis systems.

Report:

Goguen, J., Linde, C., & Bikson, T. K. (1985). Optimal structures for multimedia instruction (Tech. Rep. No. 4778). Menlo Park, CA: SRI International.

MODELING THE STRATEGIES OF MATHEMATICS STUDENTS

NR 154-508
Carnegie-Mellon University/Langley

Scientific Objectives: The goal was to find techniques to automate the diagnosis of (possibly erroneous) problem-solving strategies used by students on the basis of their performance.

Approach: The diagnostic problem was divided into three parts: To identify the problem-solving steps taken, to identify the order in which those steps were taken, and to identify the rules which generated those steps in that order. The steps involved were found by applying all possible steps backwards from the answer given by the student. The solution path was found by selectively searching through the possible orderings of these steps on the basis of psychological theory. The strategy was found by abstraction over several solution paths.

Results & Conclusions: A computer program implementing the techniques described above is completed. It has been applied to small sets of data in the domain of multi-column subtraction and it successfully diagnosed both the correct subtraction strategy and a few types of misconceptions.

Potential Applications: General, computer-implemented techniques for cognitive diagnosis could be applied to help provide individualized instruction.

Archival Publications:

Langley, P. (1985). Learning to search: From weak methods to domain-specific heuristics. Cognitive Science, 9, 217-260.

COMPUTATIONAL THEORIES OF SKILL ACQUISITION AND PROBLEM SOLVING
NR 667-477
Xerox Corporation/Brown & VanLehn

Scientific Objectives: This research tested a theory based on two main hypotheses: (1) that generalization of examples suffices to explain human skill acquisition, provided that the student utilizes the information inherent in the organization of the lesson sequence, and (2) that people execute their procedures reflectively, by modifying their execution state in certain ways not prescribed by the procedure.

Approach: The research strategy was to fit models of learning and problem-solving based on artificial intelligence technology into the traditional criteria for scientific theories. The theory' s hypotheses were formalized, along with competing hypotheses. Each version of the program was run on simulated lessons. The output, a set of predicted error types, was compared to error data from students taking those lessons. A hypothesis was accepted if its predictions were better than the predictions of the competing hypothesis.

Results and Conclusions: A variety of knowledge structures based on traditional computer-science notions of procedures has been tested, using data from students of several basic mathematical skills. Recently, the investigation has focused on revised notions of procedural knowledge. As a by-product of this research, special computational tools have been developed to manage the hypotheses, the predictions, and the arguments connecting them.

Potential Applications: The theory-managing tools can be used by any cognitive scientist with the appropriate computer resources. When complete, the theory may help improve instruction by predicting "mind bugs" and other misconceptions, by evaluating and fine-tuning curricula, and by suggesting effective lesson sequences.

Archival Publication:.

J.S. Brown (1985). Idea-amplifiers -- new kinds of electronic learning. Educational Horizons, 63, No. 3.

AN AUGMENTED COMPUTERIZED READABILITY EDITING SYSTEM
NR 667-513
University of Michigan/Kieras

Scientific Objectives: The objective was to use existing psycholinguistic data to develop principles for the design of an automated text-analysis system. The system should be able to critique and suggest revisions for a typical range of technical text.

Approach: The research plan combined an extensive analysis of the existing literature in psycholinguistics with natural language comprehension methods derived from artificial intelligence research. The combination of these two approaches yielded a principled design for an automated technical writer's aid that incorporates a deeper understanding of comprehension and natural language structure than do conventional writers' aids.

Results and Conclusions: A large number of psycholinguistics articles was summarized, and an initial set of comprehensibility rules was devised. An experiment has been conducted in which the quality of a simulated technical manual was improved by using these rules. A demonstration version of the comprehensibility system was constructed using components from earlier comprehension models. The demonstration system was able to make many useful comments about maintaining coherence and consistent terminology.

Potential Applications: Development of an actual usable system to improve the content of technical material.

Reports:

Kieras, D. E. (1985). The Potential for Advanced Computerized Aids for Comprehensible Writing of Technical Documents (TR-85/ONR-17). Ann Arbor, MI, University of Michigan, College of Engineering.

Kieras, D. E. (1985). Improving the Comprehensibility of a Simulated Technical Manual (TR-85/ONR-20). Ann Arbor, MI: University of Michigan, College of Engineering.

Kieras, D.E., & Dechert, (1985). Rules for Comprehensible Technical Prose: A Survey of the Psycholinguistic Literature (TR-85/ONR-21). Ann Arbor, MI: University of Michigan, College of Engineering.

Kieras, D. E. (1985). An augmented computerized readability editing system: Final report (TR-85/ONR-22). University of Michigan, College of Engineering.

FLEXIBILITY IN JOINT PROBLEM SOLVING: THE EFFECTS OF DIFFERENT POINTS OF VIEW ON OVERCOMING BLOCKS

NR 667-532
University of California, San Diego/Levin

Scientific Objectives: The goal was to specify the role that conceptual points of view play in problem solving, especially when a problem solver is blocked (i.e., does not know how to take the next step).

Approach: Computer-based graphics microworlds have been developed as an instructional and experimental environment for the study of problem-solving skills. These microworlds allow the experimental manipulation of point of view, as well as the measurement of changes in point of view during problem solving. Experiments have been run using these graphical microworlds and a to look at the role of point of view in individual and group problem solving.

Results and Conclusions: Several programs have been written to implement microworlds for learning and problem solving. These programs have been used in several experiments on the role of point of view in problem solving.

Potential Applications: The results of this research will be useful in the development of practical problem-solving aids and intelligent automated tutoring systems to teach problem solving skills.

Archival Publications:

Levin, J.A., & Miyake, N. (1985). Care and repair of a microcomputer. Electronic Learning, Sept.

This work is being continued under work unit NR 702-002.

M. KNOWLEDGE AND SKILL

This cluster is aimed at characterizing skilled performance in real-world tasks which demand complex information processing. Map interpretation, troubleshooting, and computer programming are three of the many possible examples of such tasks in the Navy. Expertise in these kinds of tasks is often rare and acquired with considerable difficulty after long post-instruction experience. Furthermore, the cognitive processes involved in these tasks are commonly unavailable to the consciousness of an expert, so that explicit accounts of these processes are not available for instruction of novices or for other purposes. Demands for high levels of expertise are increasing in the Navy along with the pressures on training, at the same time that the manpower pool is decreasing. This research provides explicit formal theories of crucial cognitive components of required skills. These theories constitute the foundations for selection of individuals with expert potential, training methods which can shorten the time now required for skill development, and personnel-evaluation techniques for assessing an individual' s level of expertise.

The general approach of this research is to build models of skilled performance which directly represent the relevant cognitive processes and structures. In addition, these models will have parameters which reflect the characteristics of the individual problem solver, his or her training history, and the problem-solving environment.

During its five-year history, this cluster has witnessed the development of several significant results and trends which go beyond those derived from individual efforts. One general development is a body of results on the differences between expert and novice planners and problem solvers. Investigations of experts and novices in software design, medicine, physics, and other fields show that both classes of individuals solve problems by a combination of planning by abstraction and means-ends analysis. What gives the expert an advantage is a knowledge of problem types and the appropriate memory structures for planning by abstraction.

Results of a more theoretical nature are concerned with the acquisition of problem-solving and trouble-shooting skills. Theories and models have been developed to define problem domains and their interrelations in terms of the knowledge required to solve problems in each. Computer simulations have been developed which model the acquisition of problem-solving skills via rote learning, insight, exercise, and example. There is every reason to believe that these theoretical developments can be extended to provide a theory of learning prerequisites, to apply it to the empirical work on expertise discussed above, and to provide methods for curriculum design.

Coordination among contractors in this area is facilitated by annual contractors' meetings. Meetings have been held at Berkeley in June, 1984, and the University of Washington in May, 1985. The next in this series is planned for the University of Illinois in July, 1986.

MICROPROCESSOR-BASED TRAINEE SELECTION AND SKILL TRAINING FOR HIGH WORKLOAD ENVIRONMENTS

NR 154-527

University of Pittsburgh/Schneider

Scientific Objectives: The work seeks to improve our understanding of skill acquisition and to develop more efficient computerized training procedures. The research applies automatic/controlled processing concepts to building complex information processing capabilities by incorporating modular, semi-automatic components into multiple processes.

Approach: The approach includes quantitative modeling and empirical testing. Previous empirical work has shown that automatic processes develop after extensive practice and are fast, parallel, require little attentional effort, and are difficult to modify. Here the empirical work is examining these findings in the context of microprocessor-based training of perceptual tasks (i.e., air-intercept control) and cognitive tasks (i.e., electronic troubleshooting and semantic search). The studies examine learning rate and transfer as a function of computer sequencing, training workload, computer graphics, spacing, and training trials. The theoretical work is modeling the learning process with a novel combination of concepts from multiple-access communication theory, distributed memory models, and production systems. The modeling provides quantitative predictions and interpretations of the qualitative changes that occur during training.

Progress: Empirical results illustrate that extended practice on component tasks is necessary before that component skill can be incorporated in a higher level skill. Without such training students can not deal with the memory load of performing the complex task. These results illustrate the functional relationship between resource load and practice.

Potential Applications: The procedures are being tested in training air intercept control and electronic troubleshooting. The training programs may provide more efficient training of high workload skills.

GENERAL PATTERNS OF INFERENCE

NR 667-494

Carnegie-Mellon University/Larkin & Carbonell

Scientific Objectives: The goals are to produce a prototype computer-implemented system that would use human-like general patterns of inference (together with some domain-specific knowledge) to solve a large group of problems and to teach problem-solving skills.

Approach: Object-based programming is used to create a hierarchy of both procedural and declarative knowledge. Therefore, general knowledge can be encoded just once and then used in a variety of situations.

Progress: A running system called "FERMI" demonstrates the feasibility of the approach. The structure of FERMI suggests that most of the knowledge associated with general scientific principles is procedural rather than declarative. This system forms the basis for experiments on how to teach humans general reasoning procedures. Current work is first exploring how FERMI can be extended to solve new sets of problems, and how it can use alternative mathematical strategies in doing so. Second, we are beginning to explore how FERMI's organization of knowledge can facilitate human learning.

Potential Applications: The ideas in FERMI' s design could be used to reduce redundancy and improve performance in expert systems and in instructional systems based on expert systems.

REAL TIME ASPECTS OF THINKING AND PROBLEM SOLVING
NR 667-528
University of Washington/Hunt

Scientific Objectives: Previous work (under NR 150-457, Performance in Dual Tasks) provided a model of problem solving under real-time pressures. This project extends the model to the analysis of problem solving while a person is simultaneously operating (simulated) machinery. A search is being made for parameters of the model representing individual performance in different attention-demanding situations.

Approach: A computer program simulation of real-time problem solving has been constructed. Other programs are being constructed to mimic the operation of simplified machinery, analogous to a "computer game" requiring problem solving and rapid decision-making. The simulation program is used to analyze how a person switches attention between different aspects of the "machinery operation" and problem-solving tasks. The model's predictions are compared to the data obtained from young adults who operate the "machinery," with special interest in consistent individual differences in the ability to allocate attention when faced with different types of machinery operation tasks.

Progress: A simulation program developed during the previous reporting period was used to model a wide variety of experiments in which people must decide to attend to one aspect of a stimulus while ignoring another, that would normally lead to an incompatible response. This addressed a basic issue in psychology, the question of response selection in situations where different but incompatible responses are possible. An extension of the same simulation was used to model a situation in which people did arithmetic problems while listening for the occurrence of a sound. On hearing the sound they had to respond by pressing a button, and then return to the arithmetic task. The simulation recovered the pattern of interference in activity associated with information load in the sound and the arithmetic task. The two simulations indicated that there should be a general "ability" to control one's attention'', which would not be specific to stimulus modality. A series of experiments was done in which people had to shift their attention from one to another part of the visual field, or from one to another part of the auditory field, or had to shift from doing one arithmetic task (addition) to another (multiplication). A common attention shifting ability was found that generalized across these tasks.

165

Potential Applications: In the long-term, a theory of real-time problem solving could be used to estimate mental workload during the design phase of man-machine systems. The experimental procedures we have developed could be used to identify people who cope well with multiple signals under high time-pressure.

Reports:

Hunt, E. b Richardson, M. (1985). Problem solving Under Time Constraints (TR-ONR-10). University of Washington, Psychology Department, August.

Hunt, E. (1985). Science Technology, and Intelligence (TR-ONR-9). University of Washington, Psychology Department, August.

Hunt, E. (1985). The Design of Ballantines (TR-ONR-8). University of Washington, Psychology Department, August.

GENERATIVE PROCESSES IN REPRESENTATIONS OF PROBLEMS
NR 667-534
University of Pittsburgh/Greeno & Resnick

Scientific Objectives: The goal of this project is to determine the consistency and theoretical coherence of participants' representations of physical phenomena and the processes involved in modifying these representations. (See also NR 667-544.)

Approach: Interview methods are used to determine the degree to which individuals hold consistent, "theory-like" beliefs across a variety of test situations. Subjects are asked to make predictions and give explanations for a set of situations that should evoke key principles regarding motion. Various forms of feedback designed to evoke consistency among explanations are then given and subjects are invited to review explanations. These conditions are included to assess the effects of different forms of intervention on restructuring knowledge and modifying explanations. Under some conditions, subjects take a delayed post-test to examine the longevity of restructuring provoked by feedback. Analysis of responses before and after feedback allows us to examine the extent to which general theories are guiding representations and the effects of intervention on restructuring.

Progress: Preliminary findings indicate that participants' detection of inconsistency in their own explanations depends largely on their perception of similarity between problem situations. Learners' analyses seem to be tied closely to problem conditions; different conditions evoke separate explanatory principles, and learners may not perceive their responses as inconsistent. In addition, when participants are shown how two predictions are theoretically inconsistent, they will often protect and maintain their original explanations by appealing to differentiating situational variables, These early findings are suggesting a reconceptualization of the theory-driven versus local-explanation questions with which we began. In particular, they point to the need for a formulation that focuses as much on processes of explanation formation as on the theoretical power of the particular principles that are involved.

Potential Applications: Findings will contribute to the refinement of cognitive theories of learning by clarifying processes by which complete structures of knowledge are acquired and modified. We hope to make significant contributions to instructional practice through identifying interventions that are effective in inducing major modifications in cognitive structures as well as sources of resistance to modification.

SKILLED MEMORY
NR 667-536
University of Colorado at Boulder/Ericsson

Scientific Objectives: To elaborate a theory of the real-world memory skills associated with expertise in a variety of domains. The research will determine how experts can rapidly store and recover large amounts of information, and determine how general or content-specific are their memory skills.

Approach: A number of real-world memory skills are being studied, including actors' memory for their parts, waiters' memory for dinner orders, and blindfolded chess. For each skill, a series of laboratory tasks are constructed that allow us to measure storage and retrieval times for domain-specific information. The contents of retrieval cues are systematically varied to assess the structure of the memory representation as reflected by latency and accuracy data. In addition, retrospective verbal reports on intermediate steps in the retrieval process are analyzed.

Progress: Several experiments investigating the organization of long-term memory were carried out. In one of these, actors with well-learned parts were given brief segments of their parts as cues, and were asked to report the word that immediately followed or preceded the presented segment. Cued and to-be-recalled material came either from the same sentence or from adjacent sentences. Consistent with the theory of real-world memory under investigation, between-sentence retrieval tended to take longer than did within-sentence retrieval. A second experiment revealed that both retrieval success and retrieval speed increases with the number of words contained in the cue segment.

Potential Applications: Many technical jobs in the military require similar real-world memory skills. This research should be useful in improving the efficiency of training for these jobs as well as in evaluation of the results of such training.

Reports:.

Ericsson, K.A. and Polson, P. G., (1985). A Cognitive Analysis of Exceptional Memory for Restaurant Orders (Technical Report No. 140). University of Colorado, Psychology Department, 1985.

STRUCTURAL UNDERSTANDING IN PROBLEM SOLVING: SPECIFYING AND INSTRUCTING COGNITIVE OBJECTIVES IN BASIC ELECTRICITY

NR 667-538
University of California, San Diego/Norman & Riley

Scientific Objectives: The objectives are to analyze (1) the knowledge required -for successful performance on D-C circuit problems, (2) the influence of different instructional methods on students' ability to acquire this knowledge, and (3) the relationship between this knowledge and the knowledge required to solve A-C circuit problems. A major issue concerns how general concepts lead to important gains in understanding at the outset of learning a new domain.

Approach: The approach involves a combination of theoretical analyses and empirical- study. Theoretical analyses involve the development of computer models of the knowledge underlying performance in solving circuit problems. Development of the models is guided by information obtained from thinking-aloud protocols obtained from students solving problems. Protocol analysis is the most effective available methodology for developing detailed analyses of students' performance on a variety of problem-solving tasks.

Progress: Work has begun to identify the knowledge required for successful performance on D-C circuit problems, which components of knowledge are available to students at the outset of instruction, and how this knowledge changes during instruction. Work has also begun to analyze how students can learn domain-specific concepts about D-C circuits by analogy with more general concepts that they already have available. In addition, work has begun to develop a generative theory of errors that will account for students' errors in terms of the mechanisms responsible.

Potential Applications: This research could lead to improvements in the teaching of basic electricity concepts, such as those taught in the Navy' s Basic Electricity and Electronics course,

Reports:

Riley, M. (1985). User Understanding (Technical Report, ICS Report V8504) University of California, San Diego, May 1985. (AD 157155).

COGNITIVE PROCESSES IN LEARNING PROBLEM SOLVING SKILLS FROM EXAMPLES

NR 667-539
University of Pittsburgh/Chi & Glaser

Scientific Objectives: The goal of this research is to understand how problem-solving skill is acquired as a function of how people study worked-out examples provided in textbooks. We also attempt to understand the sources of individual differences in learning to solve problems in a technical domain such as physics.

Approach: The approach used in this research is to collect elaboration protocols of students studying worked-out examples and relate the kind of inference rules they build during the studying phase with the production rules that they use to solve the problems. Students' elaboration protocols are collected while they study worked-out examples and justify each problem-solving step. In contrast to this investigation of study protocols, conventional problem-solving research has focused predominantly on problem-solving protocols themselves, thus the data generally provide a competence model rather than a learning model.

Progress: We have completed the collection of our data on 10 students learning four chapters of physics text, their protocols during the studying phase, and their protocols for solving problems that are isomorphic to the example problems as well as problems that are quite distinct from the examples.

Potential Applications: This work should provide practical advice on how to design instructional materials to be more helpful to a wider range of students, particularly in scientific and technical domains.

Archival Publications:

Glaser, R. (1985). Understanding human intelligence (Review of *Beyond IQ*), *Science*, *230*, 59-61, October.

Glaser, R. and Rabinowitz R. (1985). Cognitive structure and process in highly competent performance. In F. D. Horowitz & M. O'Brien (Eds.), *The gifted and the talented: A developmental perspective*. Washington, DC: American Psychological Association.

HUMAN UNDERSTANDING OF COMPLEX SYSTEMS
NR 667-540
Bolt Beranek & Newman, Inc./Collins

Scientific Objectives: The project has two closely related objectives: (1) to develop and refine a theory of how people's understanding of physical systems changes during learning, and (2) to develop a theory of explanation and to test which types of explanation are most effective in inducing conceptual change.

Approach: A large experiment was conducted to investigate conceptual change across three domains: home heating systems, electrical systems, and evaporation processes. Subjects in the experiments were tutored individually, and were tested in a pre- and post-test design. A tutoring system will be developed that can present material on a topic using different explanation strategies. Then a series of experiments will be run comparing the effectiveness of the different explanation strategies in a similar pre- and post-test design.

Progress: The experiment run during the year found that the most important thing that subjects acquire is an understanding about a few basic mechanisms. For the domain of evaporation the first basic mechanism is the idea of molecules in motion, which is critical to understanding differences in temperature and pressure, how molecules escape (and return) from water, and how molecules exchange energy. A second basic mechanism is the notion of molecular attraction. It plays a role in the difference between liquid and vapor, the close packing of molecules in water, the difficulty in escaping from the liquid, and the aggregation of water molecules around charged particles. These and other basic mechanisms appear to be the critical concepts the students are learning.

Potential Applications: This research is part of an important new subfield of cognitive psychology: the study of mental models. The increased understanding of mental models will impact on scientific and technical training both in the military and in the society at large. In particular, this research has strong implications for the improved design of intelligent automated instructional systems, by suggesting the most effective teaching strategies for overcoming students' prior misconceptions.

COMPUTATION VIA DIRECT MANIPULATION
NR 667-541
University of California, San Diego/Norman

Scientific Objectives: The objective of this research effort is to understand a new style of computation, computation by direct manipulation. In this form of interaction the computational demands of systems are matched to the mental structures of users and thus allow concentration upon the substantive topic domain rather than the means of computation. The goal of this project is to develop a cognitive account of both the advantages and disadvantages of this new form of computation. To accomplish this will require a deeper understanding of the role of mental representations in task performance. The development of such a theory is the primary objective of this research.

Approach: There are two underlying metaphors for interaction between humans and machines. The traditional one has been that of a conversation in which the interface serves as an intermediary between a user and a world about which things are said. A second metaphor, which underlies the notion of direct manipulations, is that of a model world. In a system built on the model-world metaphor, the interface is itself a world where a user can act, and that changes state in response to user actions. The world of interest is explicitly represented and there is no feeling of an intermediary between user and world. It is this form of interaction that we are investigating. The technical approach being taken consists of integrated theoretical, empirical, and development efforts. The development effort is primarily concerned with the design and implementation of direct-manipulation programming environments for a series of test domains. A related activity is the development of a set of computational tools to facilitate the implementation of the applications. The empirical effort involves investigating test systems in order to understand the nature and role of effective mental models and to develop analytic techniques for the elicitation and representation of these models. The theoretical effort focuses on the development of the necessary psychological principles to provide a principled understanding of direct-manipulation forms of human computer interaction.

Progress: This research is being conducted by a collaborative research group consisting of researchers from NPRDC and UCSD under the auspices of the ONR Bridges program. During the first year a joint laboratory was established. Major areas of progress are: Completion of a book on user-centered system design; development of a theoretical framework for the investigation of direct manipulation interfaces (Two phenomena which give rise to the feeling of directness of interfaces were identified. One has to do with the information processing distance between the user's intentions and the facilities provided by the machine. The other concerns the relation between the input and output vocabularies of the interface languages); development of an initial implementation of a direct-manipulation interface in the area of statistics.

Report:

Hutchins, E., Hollan, J.D., & Norman, D.A. (1985). Direct manipulation interfaces. (Technical Report ICS No. 8503). University of California, San Diego, Institute for Cognitive Science.

Archival Publication:

Hollan, J. D., Weitzman, L, & Rosenstein, M. (1985). Interface design for simulations. In Proceedings of the First Annual Artificial Intelligence & Advanced Computer Technology Conference, 357-368.

LEARNING ABOUT EQUIPMENT FROM TECHNICAL DOCUMENTATION
NR 667-543
University of Michigan/Kieras

Scientific objectives: The work focuses on how documentation specifies both procedural knowledge (information about how to operate the equipment) and also how-it-works knowledge (information about how the equipment works inside, which corresponds to providing mental model information about the equipment).

Approach: The project will use a combination of experimental data and cognitive simulation modeling. The acquisition of procedural knowledge from technical text will be investigated by careful manipulations of the structure and content of instructions to operate simple equipment. Simulation models will be constructed to represent how instructional text is translated into a correctly executing set of production rules. The model should account for features of the instructions that affect the difficulty of this translation process. The role of transfer of knowledge of previously learned procedures in this process will also be investigated. The nature of effective mental models for equipment will be investigated by the systematic manipulation of the specific knowledge supplied to the learner about how the equipment operates. Again, a cognitive simulation model should be able to account for which information is critical.

Progress: Progress to date has consisted primarily of setting up new laboratory facilities for data collection, and implementing basic tools for doing the cognitive simulation modeling. Data collection and modeling efforts are about to begin.

Potential applications: These results will be of considerable value in specifying the form and content of technical documentation for equipment.

Reports:

Kieras, David E., Bovair, Susan (1985). The Acquisition of procedures from text: A production-system analysis of transfer of training (TR-ONR-16). University of Michigan, Department of Engineering, January 1985.

Kieras, David, E (1985) The role of prior knowledge in operating equipment from written instructions (TR-ONR-19). University of Michigan, Department of Engineering. February 1985.

GENERATIVE PROCESSES IN REPRESENTATIONS OF PROBLEMS (II)
NR 667-544
University of California, Berkeley/Greeno

Scientific Objectives: The goal of this project is to characterize knowledge that supports the generation of representations in problem situations. To understand how different individuals construct different representations of the same problem, or how an individual constructs different representations in the process of working on a problem, we need a generative theory. (See also NR 667-534.)

Appraoches: A classical domain of tasks for study of problem formulation is the domain of insight problems, for which there is a large body of experimental results. One method to be used is the construction of computational models that simulate general features of these existing findings, with special attention to the knowledge and proeesses that can generate reformations of the problems. Relations will be considered between the cognitive processes in insight problems and other tasks, especially involving knowledge about physical devices, such as troubleshooting and learning operating procedures, and for predicting and explaining events in physical systems that often reveal "misconceptions" about physical principles. New tasks will be designed to enable assessment of knowledge required for a variety of tasks involving the same physical device.

Progress: A model of the knowledge needed for insight tasks has been developed, involving knowledge of methods associated with goals, functions associated with objects, and properties of functions that can be used, if necessary, to infer potential functions of objects, These knowledge structures are related significantly to principles of understanding physical devices: functional principles that generate requirements, and technological principles that generate capabilities. This scheme is being used to design a task environment that can be used to identify knowledge structures needed for varied problems such as learning operating procedures, troubleshooting, and predicting and explaining behavior of the system. In another domain, models of knowledge for representing problems in elementary programming have been formulated, clarifying properties of knowledge in the technical domain of computation that are different from knowledge brought from general experience by novices.

Potential Applications: A better understanding of knowledge required for representing problems (distinct from knowledge for solving problems that are already represented) will add to the general fund of cognitive principles that can provide significant guidance for design of instructional materials and for training individuals to perform the various tasks that are required in technical service. Specifically, understanding of relations between different kinds of tasks should assist in the design of tasks used in training when the goals of training include a variety of tasks to be performed in the field.

RESTRUCTURING AND INSIGHT IN PROBLEM SOLVING
NR 667-545
University of Pittsburgh/Ohlsson & Resnick

Scientific Objectives: The goal of this project is to integrate two seemingly contradictory theories of thinking: the Gestalt view and the information-processing theory of problem solving. The first defines problem solving in terms of a sudden reorganization of the problem leading to insight, while the second emphasizes gradual, step-by-step progress toward problem solution. A resolution to the theoretical disparity has been achieved, however, by interpreting the Gestalt concepts of restructuring and insight in information-processing terms. A computer simulation model is to be developed to test and verify theoretical findings.

Approach: A small number of participants are studied intensively while solving classical Gestalt insight tasks. Verbal protocols are obtained using the "think-aloud" method. These data are used to develop a simulation program which takes a problem description as input and provides a problem solution. Testing the simulation program with problems from a variety of task domains will reveal whether the mechanisms postulated in the integrated theory are sufficient to produce insightful behavior.

Progress: The simulation model has been designed and is currently being implemented. The program is being debugged by running it on a set of very simple problems, such as classical problem-solving puzzles, transitive inferences, blocks-world problems, etc. In order to be able to solve the classical Gestalt insight problems, a more realistic knowledge base is required; this is currently being constructed.

Potential Application: The project promises to provide greater conceptual unity to the psychology of thinking by elaborating significant convergences between two major approaches to problem solving. The results will contribute to our understanding of the processes involved in problem solving in novel problem situations.

PARALLEL DISTRIBUTED PROCESSING MODELS OF HIGHER COGNITIVE PROCESSES
NR 667-548
University of California, San Diego/Rumelhart

Scientific Objectives: The goal is to develop the concept of the mental model within the framework of parallel distributed processing theory. The idea is to conceptualize the highly cognitive notion of mental models in terms that will yield accounts that are biologically plausible and computationally sufficient.

Approach: The parallel distributed processing approach to understanding perceptual and cognitive phenomena is based on the idea that intelligent function manifests the activity of large numbers of highly interconnected processing elements possessing neuron-like properties of activation and connectivity. This idea is used in an effort to develop a computer simulation capturing important features of the notion of mental models as these might function to guide and tune complex coordinated motor activity. A key concept of this effort is the notion of a neural network which takes as input some specifications of the motor actions one intends to carry out and produces an interpretation of ''what would happen if one did that.'' Part of this specification is a specification of what the new stimulus conditions would be once the anticipated action is completed. If the anticipated new stimulus conditions are inconsistent with a desired state of affairs, then some alternative action set would be considered. This iterative process would continue until a match between desired and anticipated states of affairs is achieved.

Progress: A parallel distributed processing model exhibiting the features outlined above has been developed, and is currently being used as the basis for a computer simulation. This simulation will serve to assess the computational and psychological adequacy of the model.

Potential Applications: The model under development in this research effort has strong potential applicability in the design of robotic systems that possess adaptive flexibility in response to changing work environments.

Reports:

Rumelhart, D,, Hinton, G. E. and Williams, R.J. (1985). Learning internal representations by error propagation (Technical Report ICS No. 8506). University of California, San Diego, Institute for Cognitive Science, September 1985.

Rumelhart, D.E. and McClelland, J.L. (1985). On learning the past tenses of english verbs (Technical Report ICS No. 8507). University of California, San Diego, Institute for Cognitive Science, October 1985.

ANALOGICAL PROCESSING AND EXPERIENTIAL LEARNING IN PHYSICAL DOMAINS
NR 667-551
University of Illinois/Gentner

Scientific Objectives: Construct and test a general theory of analogical processing as it applies to learning and reasoning, and develop a computational account of how people access and process analogy and similarity.

Technical Approach: Gentner's Structure-mapping theory forms the basis for this research. Research techniques derive from both psychology and artificial intelligence. They include: (1) psychological experiments to investigate the processing of analogy and similarity; (2) computer simulation of analogical processes; (3) analyses of people's understanding of systems and of the changes that occur in understanding as a result of different experiences.

Progress: Work under this contract was begun late in FY-85 and no progress reports have yet been issued. However, this effort is a continuation of work done under an earlier sub-contract, and the publications below reflect that earlier work.

Potential Applications: By illuminating how people learn and use mental models of systems they must deal with, this research will contribute to better system design, to improved training, and to enhance maintenance ability.

Archival Publications:

Gentner, D. & Grudin, J. (1985). The evolution of mental metaphors in psychology: A ninety-year retrospective. American Psychologist, 40, No. 2, 181-192.

Forbus, K., & Gentner, D. (1985). Learning physical domains: Towards a theoretical framework. In R. M. Michalski, J. Carbonell 6 T. Mitchell (Eds.), Machine learning: An artificial intelligence approach, Vol. II. Morgan Kaufmann.

Forbus, K. (1985). Qualitative process theory. Artificial Intelligence, 24. Also published as a chapter in D. Bobrow (ed.) Qualitative reasoning about physical systems. Cambridge, MA; MIT press.

Forbus, K. (1985). The role of qualitative dynamics in naive physics. In J. Hobbs 6 R. Moore (Eds.), Formal models of the commonsense world. Tioga Press.

THE EFFECTS OF GRADUATE TRAINING ON INDUCTIVE REASONING
NR 667-552
University of Michigan/Nisbett

Scientific Objectives: The objective is to determine the effects of various kinds of graduate training on inductive and deductive reasoning. The anticipation was that the "probabilistic sciences" would improve inductive reasoning and deductive reasoning whereas nonscience fields and deterministic science fields would improve deductive but not inductive reasoning.

Approach: A test consisting of items assessing statistical and other types of inductive reasoning as well as items assessing logical and formal reasoning was administered to students just embarking on graduate education and to students who had studied for two years. The fields examined, all at the University of Michigan, were chemistry, psychology, law and medicine.

Progress: As anticipated, training in both of the probabilistic fields, psychology and medicine, produced substantial improvement in inductive and deductive reasoning. These results can be understood if we assume that the probabilistic sciences teach principles of inductive reasoning that are generally applicable, whereas nonscience fields and deterministic science fields do not teach people how to deal with uncertainty. All fields studied, however, teach people how to analyze problems in a formal way, consistent with logical requirements. A longitudinal version of the study is currently under way. The original first-year students have now completed their second year of study and have been retested. It will soon be possible to see whether the longitudinal results are the same as the cross-sectional results.

Potential Applications: It is possible that the inductive reasoning principles taught by fields such as psychology and medicine can be considerably encapsulated and taught effectively with techniques less intensive than two years' immersion in psychology or medicine. It is also possible that even the benefits conveyed by such immersion can be considerably enhanced by appropriate additional instruction.

Archival Publication:

Nisbett, R. E. b Kunde, A. (1985). The perception of social distributions. Journal of Personality and Social Psychology, 48, 297-311.

EXPLANATION AND LEARNING IN PROCEDURAL SKILLS
NR 702-009
University of Colorado/Lewis

Scientific Objectives: To understand how people use causal analysis in learning complex skills, especially skills in controlling computer systems. To use this understanding to design systems that are easier to analyze and hence easier to learn to control.

Approach: The project uses three converging approaches. First, empirical study of human learners is used to document the role of causal analysis, as revealed by learner's behavior and verbal comments. Second, a model of the analysis process, and how its results can be used to drive skilled performance, is implemented in the form of a computer program. The model is based in part on observations of human learners, and in part on rational analysis of the learning task. It serves as a statement of the evolving theory as well as providing guidance for continuing empirical study. Third, tests of the practical implications of the theory for the design of systems and the design of training methods are planned.

Progress: An initial learning model for user-computer interactions has been built, embodying three simple heuristics for identifying causal relationships. They are: identity, loose ends, and previous action. Surprisingly, these heuristics are adequate to analyze a number of common interaction patterns, without requiring any other knowledge. While it is clear that human learners often rely on specific knowledge of computer systems in learning new interactions, it is nonetheless interesting that this specific knowledge may often be logically unnecessary. Even in its present rough form the model can deal with some cases that are beyond the reach of approaches that do not use causal analysis, such as methods that modify interactions by replacing references to one action or object by another.

Potential Applications: The project may help us to distinguish clearly between user-computer interactions that can readily be understood and learned and those that require complex problem-solving or prior knowledge to master. It may also suggest how to design new forms of interactions that exploit our insight about what learners must do in mastering a new interaction. Beyond the sphere of user-computer interactions it is likely that causal analyses are involved in other skills, especially other control skills such as are involved in using any complex equipment, and that design improvements in other areas might be forthcoming. Even when interaction designs cannot be modified the project may be useful in suggesting how a skill could best be presented to a learner. It is possible that commentary that highlights the causal connections between user actions and system responses may enhance learning from demonstrations, and the project will explore this possibility.

TRANSFER OF TRAINING IN PROBLEM SOLVING
NR 702-G11
Community College of Allegheny County/Kotovsky

Scientific Objectives: The goal of the research is to obtain an understanding of factors that determine transfer of training in problem solving (that is, how solving one problem facilitates the solution of subsequently encountered problems). A second goal is to build a computer model of the transfer process.

Approach: In the early phase of the project, a number of experimental investigations of transfer will be carried out. These will involve measuring the amount of transfer obtained between pairs (and sometimes larger numbers) of problems administered at varying time intervals. The problems are sets of isomorphs of the Tower of Hanoi problem and of simple physics problems that will be presented to subjects on a computer-graphics system. They differ in their underlying move-rule similarity. As our knowledge accumulates, a computer model of the transfer process will be constructed to explore the interactions of the factors found to have a significant effect on transfer.

Progress: Work has begun on programming sets of isomorphic problems, and on developing the stimulus presentation and data collection methods. A basic stimulus presentation-data collection system is currently near completion, The first series of experiments is about to begin.

Potential Applicationsu: This work should provide guidance on the design of many instructional sequences. It should provide information that can be used to determine the makeup and sequencing of materials so as to increase the opportunities for problem-to-problem transfer, and thus for the eventual generalization of problem-solving skills.

Archival Publication:

Kotovsky, K., Hayes, J. R., 6 Simon, H. A. (1985). Why are some problems hard? Evidence from Tower of Hanoi. Cognitive Psychology, 17, 248-294.

CALIBRATION OF COMPREHENSION
NR 702-012
University of Wisconsin/Glenberg & Epstein

Scientific Objectives: When readers attempt to learn from written texts they face two problems. The first is the problem of comprehension--how to engage the appropriate cognitive processes to extract information from the text. The second problem is one of meta-comprehension--how to determine if the comprehension processes have succeeded. Our research on the meta-comprehension problem has demonstrated poor calibration of expository texts: Confidence in comprehension is poorly correlated with performance on a test of comprehension. The current research has two objectives. The first is to understand the reasons for poor calibration of comprehension. The second objective is devising training procedures to improve calibration of comprehension.

Approach: In our standard experimental procedure subjects are asked to read expository texts on different topics. Each text is one paragraph long and is composed around a central principle. Subjects are asked to judge (for each text) their confidence in ability to apply the principle. Finally, a test requiring application of the principle is given. The standard dependent variables are the confidence judgments, performance on the test, and a measure of association between the judgments and performance. These dependent measures are supplemented by others, such as reading time, when demanded by the experimental logic. Data analysis proceeds through a combination of ANOVA and multiple regression. The regression analyses are useful when dealing with individual-difference variables measured on continuous scales.

Progress: Two findings, based on preliminary research, appear significant. First, in the absence of specific feedback, subjects are poor at predicting performance on all types of comprehension tests. However, experience in answering questions specific to a given text enhances predictions of future performance. Second, experts in a given domain are no better calibrated in that domain than are novices. Internal analyses of the data suggest that experts predict future performance on the basis of their self-classification as experts, not by assessing knowledge acquired from specific texts.

Potential Applications: The applications of this work are not limited to the conventional student population. There are many non-school settings in which people are required to engage in frequent updating to keep pace with developing technologies or shifting missions. In these cases, awareness of the need to train self-monitoring and to improve calibration may contribute to less stressful and more efficient operations.

COMPREHENSION PROCESSES IN MECHANICAL REASONING
NR 702-014
Carnegie-Mellon University/Just & Carpenter

Scientific Objectives: This research aims to analyze the process by which a reader of texts describing mechanical systems constructs an internal representation of the mechanisms in order to operate, repair or assemble the mechanism later on. Further, the research aims to determine how the properties of texts and diagrams, as well as the cognitive abilities of the reader, affect this process.

Approach: Modified versions of texts from Basic Machines, a Navy training manual, will be used in the research. Characteristics of the text, the diagrams, and the relation between the two, will be experimentally varied. Records of eye movements by readers will provide data for making inferences about processing, particularly identification of points of maximum processing load. A computer simulation will be produced that builds up a"mental model" of the mechanism. This simulation will be based upon existing simulations of text processing and of the processing of spatial ability test items.

Progress: This is a new contract, and no Status Reports have yet been issued.

Potential Applications: This research should lead to methods (possibly automated) and guidelines for both the effective use of diagrams in relation to text and for determining whether procedural instructions contain sufficient and appropriate information to permit adequate understanding.

EFFECTS OF SECOND-LANGUAGE PROFICIENCY ON LEARNING FROM TEXTS
NR 702-015
University of California, Santa Barbara/Duran & Goldman

ScientificObjectives: The overall objective is to characterize the cognitive processes of linguistic minority trainees as they comprehend and reason from instructional texts. This includes the identification of linguistic structures that are likely to cause difficulty, as well as the investigation of the impact of lower-level aspects of comprehension upon more sophisticated inferential processing of instructional texts.

Approach: Texts from a variety of subject-matter areas are being analyzed with respect to structures at the sentence, inter-sentence, and global level. Quantifiers, qualifiers, conditionals, and linguistic features signaling cohesion among parts of a text are being emphasized. Students are presented with academic tasks varying in their demand for sophisticated cognitive processing, and are asked to "think aloud" as they perform the tasks in order to identify points of processing difficulty. Exploratory studies during the early phase of the contract will lead to hypotheses to be tested experimentally in later phases.

Progress: This is a new contract.

Potential Applications: Members of linguistic minorities, primarily Hispanic Americans, constitute a large and increasing proportion of potential naval personnel. This research is aimed at understanding how limitations of linguistic proficiency -- even among personnel who seem relatively proficient -- can interfere with thorough comprehension of training materials and prevent success in technical training. Guidelines for appropriate design of training materials are one expected payoff of this research.

* * * * * *

THE FOLLOWING WORK UNITS WERE COMPLETED DURING THE PAST YEAR:

EVALUATION OF THE ABILITIES OF MARINE ENGINEERING PERSONNEL TO DETECT, DIAGNOSE, AND COMPENSATE FOR SYSTEM FAILURES

NR 154-491
Georgia Institute of Technology/Rouse

Scientific Objectives: The goal was to investigate human problem-solving behavior and its relation to simulator fidelity. A principal objective was to determine the levels of fidelity most appropriate for learning the cognitive skills characteristic of expert troubleshooters.

Approach: Marine engineering personnel in training at Marine Safety International, Inc., were studied as they detected, diagnosed, and responded to system failures in a high-fidelity simulation of a supertanker powerplant. Behavior was also studied in the context of computer-based low and moderate-fidelity simulators. The relations among performance with simulators at different fidelity levels was analyzed. Measures of problem-solving performance, system knowledge, and individual ability were taken. Results were used to refine a rule-based model of diagnostic reasoning and problem solving.

Results and Conclusions: Fidelity can be characterized along physical, structural, and dynamic dimensions. Pattern recognition, graph-theoretic, and control-theoretic methods, respectively, are appropriate for developing quantitative measures of fidelity along each of these dimensions. Research on modeling engineered systems and building intelligent simulator-based training systems can benefit from a combination of qualitative reasoning methods and exact methods based on differential equations. A hybrid language of formalism for simulating large dynamic systems is needed also for the development of intelligent aids to real-time problem solving. Accurate expert performance in diagnostic tasks depends upon a combination of task-specific system knowledge and generic problem solving strategies. Individual differences in both these areas can be measured and related to differences in task performance.

Potential Applications: Marine powerplant failures which cannot be handled by automated subsystems are usually complex. They require highly developed skills for timely detection, diagnosis, and compensation. Simulators are central to effective training, yet the cost of high-fidelity simulators limits the number of personnel who can be effectively trained. This research has broad applications to improving the cost-effectiveness and availability of simulator-based training by providing scientifically based design principles for less expensive simulators which can be implemented on microcomputers or AI work stations.

Reports:

Rouse, W. B., b Morris, N. M. (1985). On looking into the black box: Prospects and limits in the search for mental models (Tech. Rep. No. 85-2). Atlanta, GA: Georgia Institute of Technology, Department of Psychology.

Su, P.-L. D. (1985). Modeling fault diagnosis performance on a marine powerplant simulator (Tech. Rep. No. 85-3). Atlanta, GA: Georgia Institute of Technology, Department of Psychology.

Archival Publication:

Govindaraj, T., Ward, S. L., Poturalski, R. J., & Vikmanis, M. M. (1985). An experiment and a model for the human operator in a time-constrained competing task environment. IEEE Transactions on Systems, Man, and Cybernetics, SMC-15, 496-503.

INTELLIGENT INSTRUCTIONAL METHODS FOR TEACHING PROCEDURAL SKILLS
NR 154-493
BBN Laboratories/Feurzeig & Frederickson

Scientific Objectives: The objective was to test a model of the knowledge and reasoning processes used by high-level expert electrical system troubleshooters, and to use this model as the basis for the design of an instructional system for teaching qualitative and quantitative problem-solving skills.

Approach: Detailed studies of expert electrical system troubleshooters were carried out. A model of expert troubleshooting and a qualitative causal model of circuit operation were developed and refined. These models were used to demonstrate correct diagnostic procedures to students and to explain the operation of circuits in faulted and unfaulted conditions.

Results and Conclusions: This project resulted in the formulation and implementation of an instructional approach based on a carefully designed sequence of qualitative causal knowledge structures, or "mental models." Each mental model in the sequence is adequate to solve a well-defined set of problems. Thus, the sequence represents an explicit characterization of the earliest levels of novice understanding, intermediate levels of systematic but incomplete understanding, and advanced levels of expertise. The instructional system also incorporates a simulated expert system, which can solve circuit problems while explaining its actions graphically and verbally (by voice synthesis). These results demonstrate the objective characterization of mental models at different levels of understanding, as well as the utility of such models in the design of instructional systems.

Potential Applications: The computer-based instructional methods and qualitative causal modeling techniques could have wide applicability for training complex procedural and diagnostic skills. Further, the particular approach to training electrical troubleshooting appears to be relatively easy to learn, and to be compatible with existing courses on electrical systems and their maintenance.

Reports:

White, B. Y. & Frederickson, J.R. (1985). QUEST: Qualitative understanding of electrical system troubleshooting. Cambridge, MA: BBN Laboratories.

Frederickson, J.R., & White, B.Y. (1985). A system for teaching a qualitative understanding of electrical circuit behavior and troubleshooting. Cambridge, MA: BBN Laboratories.

THE ROLE OF PRIOR KNOWLEDGE IN OPERATING EQUIPMENT FROM WRITTEN INSTRUCTIONS
NR 667-473
University of Arizona/Kieras

Scientific Objectives: This project investigated the role of three kinds of prior knowledge: previous knowledge of equipment in general, such as electronics experts would have; prior knowledge of how the equipment works inside, as in a mental model for the equipment; and prior knowledge of some of the operating procedures.

Approach: Electronics experts were compared to ordinary subjects in tasks involving describing equipment, or operating it according to instructions. Subjects who knew a mental model for a fictitious device were compared with those who didn't in terms of their ability to learn, or infer, how to operate the device. Prior knowledge of procedures was studied by careful manipulations of the order in which subjects learn procedures. In all three topic areas, a key approach was to develop a cognitive simulation model of the processes subjects are performing, and then to compare the model to the behavioral data.

Results and Conclusions: The major results can be summarized as follows: Knowledge of equipment in general is very complex, but does not seen to include many stereotyped procedures. Experts can be misled by their knowledge when dealing with unfamiliar equipment in instruction-following situations. A mental model for a device is valuable only if it enables the user to infer the exact procedures for operating the device. A simulation model successfully represents this process. Transfer of training from previously learned procedures can be predicted very accurately based on a formal description of the procedural knowledge required.

Potential Applications: The results of expertise in instruction-following are important for the design of computerized maintenance aids. The mental model and transfer results suggests possible improvements in training and reference materials.

Reports:

Kieras, D., & Bovair, S. (1985). The acquisition of procedures from text: A production-system analysis of transfer of training (Technical Report No. 16). University of Michigan, Department of Psychology.

Kieras, D. E. (1985). The role of prior knowledge in operating equipment from written instructions: Final Report (Technical Report No. 19). University of Michigan, Department of Psychology.

Archival Publication:

Kieras, D. E. (1985). The why, when, and how of cognitive simulation: A tutorial. Behavior Research Methods Instruments, & Computers, 17, 279-285.

EXPERT PROGRAMMER COMPREHENSION OF REALISTIC COMPUTER PROGRAMS

NR 667-503
University of Chicago/Pennington

Scientific Objectives: The goal was to test and refine a theory of expertise and knowledge representation in the domain of computer programming. This project focused on experienced, expert programmers rather than novices.

Approach: Exploratory and experimental methods were used to study the comprehension of and memory for computer programs. Moderately long, realistic programs were constructed in FORTRAN and COBOL. These programs were then used in think-aloud protocol, free recall, and cued recall experiments. Recall and recognition accuracy, inter-response times, and conceptual clustering were measured. This multivariate approach allowed cross-checking of hypotheses about memory structures underlying expert performance.

Results and Conclusions: Computer programming and other design tasks can be analyzed in terms of multiple abstractions which interact to form the meaning of the designed structure. Thus, comprehension of the final form of a program required retrieval and integration of multiple sets of relations among parts. Experiments tested which, if any, representations are dominant in the comprehension of programs by experts; specifically whether procedural (control flow) or functional (goal hierarchy) relations predominate. Results of these experiments agree with other data from studies of text comprehension: procedural units are most salient.

Potential Applications: Programming language and software systems designers should benefit from a better understanding of the ways programmers think. Improvement in language design, educational practices, and programming aids are needed to overcome the current software crisis, which is very costly to the military and to industry.

Report:

Pennington, N. (1985). Stimulus structures and mental representations in expert comprehension of computer programs (Tech. Rep. No. 2-ONR). University of Chicago.

INDEX

CONTRACTORS

Advanced Statistical Technologies Corporation, 109
Allegheny County Community College, 169
Alphatech, Inc., 33, 41
American College Testing Program, 103, 113, 114
Arizona, University of, 69, 89

Bolt, Beranek & Newman, Inc., 89, 135, 149, 161, 173
Brandeis University, 18, 126
Brown University, 127

California Institute of Technology, 17
California, University of, Berkeley, 19, 136, 164
California, University of, Irvine, 16, 145
California, University of, San Diego, 122, 143, 154, 160, 162, 166
California, University of, Santa Barbara, 171
Carnegie-Mellon University, 34, 125, 137, 139, 140, 145, 151, 152, 156, 171
Catholic University of America, 5
Chicago, University of, 28, 100, 115, 175
Colorado, University of, 26, 142, 148, 168
Colorado, University of, Boulder 159
Connecticut, University of, 33, 68

Decision Science Consortium, 41, 46
Duke University, 25, 62, 91

Eastern Virginia Medical Authority, 85
Educational Testing Service, 102, 107, 109, 116
Engineering Research Associates, Inc., 109

General Electric Company, 10
George Mason University, 6
Georgia Institute of Technology, 81, 172

Harvard University, 71, 126, 128
Haskins Laboratories, 122
Human Resources Research Organization, 83

Illinois, University of, 53, 97, 99, 105, 123, 167
Illinois, University of, Chicago, 101
Iowa, University of, 87, 98, 112

Johns Hopkins University, 36, 51, 110

Maryland, University of, 38, 74, 88
Massachusetts Institute of Technology, 4, 14, 20, 34, 45, 60
Mental Research Institute, 84
Michigan, University of, 22, 141,
Minnesota, University of, 50, 69
Missouri, University, 107, 108

National Research Council, 8
National Opinion Research Center, 80
Naval Ocean Systems Center, 17, 42
New Mexico State University, 3
New York University, 21
New York, State University of, 63
North Carolina, University of, 73
Northwestern University, 58

Oregon, University of, 15, 124

PAR Technology Corporation, 7, 37
Pennsylvania State University, 61

INDEX

CONTRACTORS

Pennsylvania, University of,
71, 83, 90, 119
Perceptronics, Inc., 38, 43, 135
Performance Measurement
Associates, Inc., 9
Pittsburgh, University of, 11, 129,
138, 147, 150, 156, 158, 160, 165
Portland State University, 104
Purdue University, 52, 75

Rensis Likert Associates, Inc., 86
Rice University, 30

San Diego State University, 147
Sloan-Kettering Cancer Research
Institute, 111
Smithsonian Institution, 78
Southern California, University of,
44, 121
Stanford Research Institute
International, 151
Stanford University, 29, 144

Technion-Israel Institute of
Technology, 123
Tennessee, University of, 96
Texas A&M University, 67, 86,92
Turing Institute, 87

Visual Intelligence Corporation, 47

Washington, University of, 79, 124, 157
Wisconsin, University of, 27, 59,
170

Xerox Corporation, 137, 152

Yale University, 54, 66, 120,
130, 134, 146

INDEX

PRINCIPAL INVESTIGATORS

Adelman, L., 37
Alderfer, C., 54
Allgaier, G., 42
Anderson, J.R., 140
Archer, R.P., 85
Athans, M., 34

Bailyn, L., 60
Baggett, P., 142
Barnes-Farrell, J.L., 68
Beach, L.R., 79
Beck, J., 15
Bejar, I., 116
Bock, R.D., 80, 100, 115
Boehm-Davis, D., 6, 10
Bowers, D., 86
Braddock, J.H., 51
Brett, J., 58
Brown, J.S., 137, 150, 152

Carbonnell, J., 156
Carlson, J., 103
Carpenter, P., 119, 171
 150, 158, 164
Carroll, V.P., 83
Castanon, D., 33
Chi, M.T.H., 160
Chinnis, J.O., Jr. 41, 46
Christensen-Szalanski, Jr., 79
Chu, Y., 135
Clancey, W.M., 144
Cohen, M.S., 46
Collins, A.M., 161
Connelly, E.M., 9
Connolly, T., 69
Cooper, L.A., 127, 129
Coyne, J.C., 84
Crain, R.D., 51

Daft, R.L., 67
Deutsch, S., 8
Donchin, E., 123
Dunham, R., 59
Duran, R., 171

Eddins, J.M., 105
Einhorn, H.J., 28
Elman, J.L., 122
Entin, E., 33
Ephremides, A., 38
Epstein, W., 170
Ericsson, A., 159

Feurzeig, W., 173
Fischer, G., 8
Fischhoff, B., 38
Fischer, C.D., 85, 92
Fredericksen, J., 89
Fredericksen, J.R., 107

Garibaldi, A.M., 50
Gentner, D., 167
Gerrard, M., 87
Gibbons, R., 101
Glaser, D., 19
Glenberg, A.M., 170
Coguen J.A., 151
Goldman, S., 171
Gopher, D., 123
Gordon, H.W., 11
Greeno, J.G., 150, 158, 164
Green, B., 110
Griffin, R.W., 67

Hackman, J.R., 66
Hammill, B., 36
Hammond, K.R., 26
Hayes, J.R., 145
Heifetz, R., 71
Heller, J.I., 136
Hildreth, E., 20
Hoffman, D.D., 16
Hogarth, R.M., 28
Howard, J.H., 5
Howell, W.C., 30
Hummel, R.A., 21
Humphreys, L., 99
Hunt, E., 157

Ilgen, D.R., 75

James, L.R., 81
Jenson, D.E., 34

Johnson, D.W., 50
Jones, D., 109
Just, M., 171

Kahneman, D., 29
Karis, D., 123
Keele, S.W., 124
Kelso, J.A.S., 122
Kibler, D., 145
Kieras, D.E., 89, 141, 153, 163, 174
Kleinman, D.L., 33
Koch, W., 20
Kosslyn, S.M., 126, 128
Kotovsky, K., 169

Landy, F.J., 21, 61
Langley, P., 151
Larkin, J.L., 156
Latane, B., 73
Lehner, P.E., 7
Lesgold, A.M., 138
Levis, A., 34
Levin, J.A, 143, 154
Levine, M., 97
Lewis, C., 168
Linn, R.L., 97
Lopes, L.L., 27
Lord, F.M., 102

MacGregor, D., 173
Madni, A.M., 43
Makowski, A., 38
Marshall, S., 147
McClelland, J.L., 122
Mislevy, 109
Morey, R., 91
Morse, A.C., 47

Navon, D., 141
Nelson, S., 4
Niblett, T., 167
Noble, D., 35, 41, 160, 162
Norman, D.A., 141, 160, 162
Novick, M.R., 112

Ohlsson, S., 165
Oppenheim, L., 71

Paulsen, J.A., 104
Payne, J., 25
Pennington, M., 175
Poggio, T., 20
Posner, M.I., 124

Reckase, M.D., 103, 113, 114
Rader-Charney, L., 139
Reif, F., 136
Reigelhaupt, D.E., 83
Rice, R.W., 63
Richards, W., 14
Rouse, W.B., 172
Rumelhart, D., 166

Saltzman, E.L., 122
Samejima, F., 96
Sarason, I.G., 79
Schein, E.J., 60
Schneider, B., 74, 88
Schneider, W., 156
Schofield, J., 147
Schoorman, F.D., 74
Serfaty, D., 33
Sheridan, T.B., 4, 45
Sinaiko, H.W., 78
Smith, E.D., 149
Smith, E.R., 52
Soloway, E., 134
Speckman, P., 108
Spoehr, K.T., 149
Staszewski, J.J., 125
Stephenson, S., 90
Sternberg, R.J., 120, 130
Stevens, K.A., 15
Stout, W., 99

Tatsuoka, K.K., 105
Todd, J.T., 105
Towne, D., 44, 121
Triandis, H.C., 53
Tsui, A.S., 62
Tsutakawa, R.K., 107
Tucker, L., 99
Turvey, M.T., 122
Tversky, A., 29

Ullman, S., 14
Uttal, W.R., 17, 22

Van de Ven, A., 69
Van Essen, D., 17
Van Lehn, K., 137, 152
Van Maaneen, J., 60

Wang, M., 98
Wohl, J.C., 41
Wong, C., 111

Yoerger, D.R., 45
Yogev, S., 58

INDEX

WORK UNIT NUMBERS

NR 150-466, 104
NR 150-467, 96
NR 150-469, 129
NR 150-474, 113
NR 150-476, 119
NR 150-480, 126
NR 150-495, 105
NR 150-499, 114
NR 150-518, 97
NR 150-520, 102
NR 150-521, 112
NR 150-522, 109
NR 150-531, 103
NR 150-533, 99
NR 150-534, 110
NR 150-535, 107
NR 150-536, 111
NR 150-537, 108
NR 159-538, 101
NR 150-539, 109
NR 150-541, 100
NR 150-542, 98

NR 154-461, 149
NR 154-486, 135
NR 154-491, 172
NR 154-492, 134
NR 154-493, 173
NR 154-497, 150
NR 154-500, 151
NR 154-502, 135
NR 154-505, 130
NR 154-508, 151
NR 154-519, 89, 135
NR 154-522, 136
NR 154-527, 156
NR 154-531, 116
NR 154-533, 119
NR 154-534, 120
NR 154-535, 137

NR 170-032, 78
NR 170-906, 53
NR 170-911, 60
NR 170-912, 66
NR 170-926, 61
NR 170-943, 54
NR 170-949, 71
NR 170-950, 67
NR 170-954, 73
NR 170-956, 58
NR 170-958, 74
NR 170-959, 59
NR 170-960, 68
NR 170-961, 75
NR 170-963, 62
NR 170-964, 63
NR 170-965, 69
NR 170-966, 69
NR 170-967, 50
NR 170-968, 51
NR 170-969, 52
NR 170-970, 71

NR 196-167, 8
NR 196-170, 3
NR 196-179, 4
NR 196-182, 5
NR 196-183, 10
NR 196-186, 11
NR 196-188, 14
NR 196-189, 15
NR 196-191, 6
NR 196-194, 16

NR 197-063, 25
NR 197-970, 22
NR 197-073, 26
NR 197-074, 30
NR 197-078, 7
NR 197-079, 27
NR 197-080, 28
NR 197-081, 29
NR 197-083, 17
NR 197-084, 17
NR 197-088, 18
NR 197-089, 19

NR 460-001, 41
NR 460-002, 41
NR 460-009, 42

NR 475-003, 70
NR 475-004, 91
NR 475-009, 79
NR 475-014, 79
NR 475-018, 80, 115
NR 475-019, 92
NR 475-026, 81
NR 475-027, 83
NR 475-029, 83
NR 475-031, 84
NR 475-032, 85
NR 475-036, 85
NR 475-037, 86
NR 475-039, 87
NR 475-041, 87
NR 475-042, 88

NR 503-001, 43
NR 503-003, 44

NR 512-001, 45

NR 535-001, 121

NR 649-001, 33
NR 649-003, 34
NR 649-004, 34
NR 649-005, 35

NR 662-004, 38

NR 667-473, 174
NR 667-477, 152
NR 667-480, 126
NR 667-483, 122
NR 667-494, 156
NR 667-503, 175
NR 667-509, 122
NR 667-510, 123
NR 667-513, 89, 153
NR 667-523, 124
NR 667-524, 138
NR 667-528, 157
NR 667-529, 139
NR 667-530, 140
NR 667-532, 154
NR 667-534, 158
NR 667-536, 159
NR 667-538, 160
NR 667-539, 160
NR 667-540, 161
NR 667-541, 162
NR 667-542, 122
NR 667-543, 163
NR 667-544, 164
NR 667-545, 165
NR 667-546, 141
NR 667-547, 141
NR 667-548, 166
NR 667-549, 125
NR 667-551, 167
NR 667-552, 167
NR 667-553, 107

NR 670-462, 127
NR 670-465, 128

NR 686-001, 36
NR 686-003, 37
NR 686-004, 38

NR 702-001, 142
NR 702-002, 143
NR 702-003, 144
NR 702-005, 145
NR 702-006, 145
NR 702-007, 146
NR 702-009, 168
NR 702-010, 147
NR 702-011, 169
NR 702-012, 170
NR 702-013, 147
NR 702-014, 171
NR 702-015, 171
NR 702-016, 148

NR DIP-252, 138

NR DSA-009, 47
NR DSA-010, 46

NR SRO-202, 20
NR SRO-203, 21